APPENDIX I

GROUNDWATER ANALYSIS

Draft Environmental Impact Statement
Allocation of Water Supply and
Long-Term Contract Execution
Central Arizona Project

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APPENDIX I GROUNDWATER ANALYSIS

This appendix describes the analyses performed to evaluate impacts of the proposed allocations on groundwater levels and quality, and the potential for subsidence. The analyses rely on published data and utilize standard methods. The analyses were prepared for several large areas that include a number of entities which would receive allocations of Central Arizona Project (CAP) water under the alternatives. These large analysis areas are the Pinal/Salt River Valley area, the Tucson area, and the Avra Valley area. For other entities, analyses were prepared to evaluate each individual entity (San Carlos Apache Tribe (SC Apache Tribe), Navajo and Hopi Indians, Tonopah Irrigation District (TID), Cave Creek, and Chaparral).

The groundwater analysis was developed to address issues raised in the scoping process with regard to how reallocation of CAP water could impact the groundwater resources. The analysis needs to have sufficient resolution to define impacts on possible recipients of CAP water and the relative impacts between different potential recipients. At its most fundamental level, the groundwater analysis must address identification of the continued availability of groundwater to entities in the future. The analysis focuses on identifying the impacts of the federal action on allocation of CAP water and does not focus on evaluating the details of plans for future groundwater development and use by potential CAP recipients that are not part of the Federal action. For example, the analysis does not attempt to evaluate potential impacts relating to alternative siting of required wells or prioritization of the use of existing wells.

The first section of this appendix discusses the methodology used to evaluate groundwater level impacts, water quality impacts, and subsidence impacts. This is followed by a discussion of how the inputs to the hydrologic inventory analysis drive the observed groundwater level impacts. The remainder of the appendix addresses specific geographic areas considered in the analysis, including discussion of existing conditions and estimated future conditions under the No Action, Settlement, and Non-Settlement Alternatives.

I. ANALYSIS METHODOLOGY

The sub-sections which follow discuss the methodology used to estimate impacts to groundwater levels, groundwater quality, and subsidence. The hydrologic inventory method used to estimate groundwater levels and the methods used to estimate the inputs to the hydrologic inventory are presented first. The methodologies used to evaluate potential water quality and subsidence impacts, which depend in part on the estimated groundwater level impacts, are then presented.

I.A. Hydrologic Inventory Methodology

Groundwater levels were analyzed using the hydrologic inventory method of analysis, in which the components of recharge to and discharge from groundwater are quantified to estimate the change in groundwater storage and related change in groundwater levels. This section discusses the rationale for selection of the hydrologic inventory as the method of analysis, the hydrologic inventory methodology, and the limitations of that method.

I.A.1. Selection of Analysis Methodology

The hydrologic inventory method was selected to evaluate impacts and implemented by developing spreadsheets to perform the required computations. The primary alternative method of analysis which was considered was the use of numerical groundwater models. Development of such models was beyond the scope of this process. However, consideration was given to the use of existing models (where available) to perform the analyses. Existing models include the following:

- **WESTCAPS Model –** This model was originally developed by the ADWR and was refined during studies performed by the Reclamation on potential future groundwater conditions in the West Salt River Valley.

- **Pinal AMA Model –** This model was developed by the ADWR to evaluate groundwater conditions in the Pinal AMA.

- **Tucson Area Model –** This model was developed by the USGS to evaluate groundwater conditions and future subsidence potential in the Tucson area.

- **Avra Valley Model –** This model was developed by the USGS to evaluate groundwater conditions and future subsidence potential in the Avra Valley.

- **Hopi/Navajo Model –** This model was developed by the USGS to evaluate groundwater conditions in the N-Aquifer underlying the Hopi/Navajo lands.

Each of the existing numerical models offers the ability to perform more extensive and detailed evaluations of the groundwater impacts, relative to the hydrologic inventory analysis. These models have also been published and are subject to public review.

The decision to use a simpler hydrologic inventory analysis rather than existing numerical models was made on the basis that:

- The numerical models would be relatively difficult to use in the short time frame available for these studies;

- The additional capabilities of the numerical models, while critical in many applications, are not required to address the more regional groundwater issues to be considered in this analysis; and

- The uncertainties in defining detailed inputs to the models over the relatively long 50-year analysis period would significantly limit the utility of the additional capabilities of the numerical models.

Uncertainties in defining the inputs to the numerical models over the 50-year period become a greater concern as the level of detail in those inputs increases. For example, prediction of the potential need for groundwater within an entity in the future would tend to be more reliable than a prediction of specific plans for recovery of the water.

While the existing numerical models were not used directly in the analysis, the documentation of the available models was used as a primary source of data to develop the hydrologic inventory analyses.

I.A.2. Hydrologic Inventory Analysis

Groundwater levels were evaluated through consideration of the hydrologic inventory. Quantified estimates of the various components of recharge to and discharge from the groundwater are used to evaluate the change in groundwater storage. The change in groundwater storage is then used to estimate the associated change in groundwater level. The hydrologic inventory was evaluated on an annual basis, and the resulting groundwater levels represent the average groundwater levels in the impacted area. This provides a general assessment of the groundwater level impacts, but it is noted that localized groundwater levels may vary from the sub-area average.

Typical components of the hydrologic inventory include:

- ♦ Recharge
    - Percolation from streams
    - Incidental recharge (from M&I and agricultural uses) and canal seepage
    - Mountain front recharge
    - Groundwater inflow
    - Artificial recharge

- ♦ Discharge
    - Phreatophyte consumptive use
    - Discharge to springs
    - Groundwater outflow
    - Groundwater pumping

The hydrologic inventory, while evaluated for groundwater, needs to consider the water demands and the surface water supplies used to meet those demands. For example, the volume of groundwater pumping can be estimated as the demands which are not met with surface water supplies within legally prescribed limits. Also, the surface water supplies contribute to incidental recharge and canal seepage.

In general, interactions between groundwater and surface water (i.e., stream percolation and rising water contributing to stream flows) and phreatophyte consumptive use are input directly to the hydrologic inventory, reflecting available data to estimate these values. However, these interactions are particularly significant and variable along the Gila and Salt Rivers, and the analysis for the Pinal/Salt River Valley attempts to estimate these quantities to reflect the groundwater conditions. This additional analysis for that area (discussed in further detail in the subsection which addresses the Pinal/Salt River Valley area analysis) provides flexibility in the analysis to reflect the changing groundwater/surface water interactions.

Sub-areas were defined for the large analysis areas. For example, Figure I-1 depicts sub-areas used for the Pinal/Salt River Valley analysis. Hydrologic inventories were evaluated for each sub-area. Sub-areas were defined in order to provide sufficient detail in the analysis to identify impacts for specific entities and to allow the groundwater flow pattern to be reflected.

The groundwater underflows between sub-areas are computed, using Darcy's Law, by multiplying the aquifer transmissivity by the width of the boundary between the sub-areas and the hydraulic gradient (i.e., the slope of the groundwater surface). The hydraulic gradient is computed in the analysis by dividing the difference in average groundwater elevations between the two sub-areas under consideration by the approximate distance between the centroids of the sub-areas. In addition to underflows between sub-areas, consideration is given to groundwater inflows from areas outside of the hydrologic inventory analysis into sub-areas. One of the assumptions of this analysis is that the aquifer transmissivity is constant. However, the transmissivity of an unconfined aquifer is at least in part a function of the saturated thickness of the aquifer, with the transmissivity declining with declining groundwater levels.

The change in groundwater storage, computed in the hydrologic inventory as the difference between total recharge and total discharge, can then be used to estimate the resulting change in groundwater elevation. This is accomplished by dividing the change in groundwater storage by the area in which the change in storage occurs (generally the acreage of the sub-area used for the analysis), and by the specific yield of the aquifer (i.e., the volume of groundwater yielded by draining a unit volume of aquifer material by gravity).

The hydrologic inventories evaluate groundwater levels essentially assuming conditions as a single unconfined layer. While there may be several aquifer units underlying some sub-areas, in general, the deeper zones would be in hydraulic continuity with the upper unconfined zones. In particular, the finer grained materials tend to "pinch out" at the margins of the basins, and most sub-areas extend into these areas where deeper zones would be connected with the upper unconfined zones. Based on this, the unconfined aquifer assumption is considered reasonable for this analysis.

I.A.3. Limitations of the Hydrologic Inventory Analysis

The hydrologic inventory analysis, while appropriate for the objectives of this study, does have some significant limitations that should be recognized in interpreting the results. Key limitations of the analysis methodology include:

- **Large sub-areas used for analysis –** The analysis is performed for relatively large sub-areas. Groundwater level impacts identified represent average impacts within these sub-areas, and the analysis does not consider the variability in groundwater conditions within each sub-area.

- **One-year time step –** The use of a one-year time step in the analysis precludes identifying seasonal changes in groundwater levels due to either natural variations in hydrology or changes in pumping and recharge patterns during the year.

- **Simplifying assumptions used to characterize the aquifer –** The aquifer systems evaluated are relatively complex, typically consisting of multiple aquifers and with aquifer parameters that vary laterally and vertically, and which can vary depending on the groundwater levels. The hydrologic inventory evaluates the aquifers essentially as single layer systems. While lateral variability in aquifer parameters can be reflected (at least at the scale of the sub-areas), the hydrologic inventory analysis does not reflect vertical variations in the aquifer parameters and how they could change with changing groundwater levels.

- **Less rigorous evaluation of some technical issues –** An example is that hydraulic gradients used to estimate groundwater underflows between sub-areas are evaluated based on the groundwater levels in the prior year. In contrast, numerical groundwater models typically "balance" the groundwater flows for the period being evaluated through an iterative process.

These limitations are generally of limited concern in identifying the regional impacts of concern in this study, but do limit the utility of these results if used outside of the context and scope of this study.

Particular caution is needed in directly comparing these results with projections prepared for other studies, particularly studies that are addressing groundwater operations at a finer geographic or temporal scale. Also, the assumed future water demands and water supplies are a dominant factor in estimating potential future groundwater levels, and the future conditions assumed in this study differ from those in other analyses. An important factor in the analysis of CAP allocation impacts is that assumptions on groundwater demands and supplies need to be consistent for the many different areas considered. The projection assumptions used in this analysis, therefore, would tend to have some differences from projection assumptions used in other studies. These different assumptions do not represent any improvement in the projections; rather, they reflect that the purpose of this analysis is different from the purposes of other analyses performed with numerical groundwater models.

I.B. Methodology to Estimate Hydrologic Inventory Inputs for Evaluation Alternatives

A methodology was developed to estimate hydrologic inventory inputs for the 2001 to 2051 period. This analysis involved estimating the future water demands for sub-areas, and the water supplies which would be used to meet those demands. Based on that information, groundwater pumping and recharge were estimated and used as inputs to the groundwater hydrologic inventory.

The inputs for the hydrologic inventory reflect the background assumptions discussed in detail in Appendix A, including assumptions on the following:

- Amount of CAP water available;

- Distribution of CAP water among the M&I, Indian, and non-Indian Ag (NIA) sectors;

- Build-out schedules for development on Indian lands;

- Distribution of excess water.

Much of the methodology to estimate hydrologic inputs is concerned with "fleshing out" the background assumptions with some additional detail, in order to identify a breakdown of supply and demand for the sub-areas used for the groundwater analysis. In addition to the information contained in Appendix A, the development of the hydrologic inputs also incorporates information discussed in detail in:

- Appendix C – Discussion of the basis for the estimated future water use by municipalities and private water providers;

- Appendix D – Discussion of the economic basis of changes in demand by NIA;

- Appendix L – Water use by the Indian sector.

It is also noted that supply and demand were estimated throughout the various groundwater analysis areas. This involved projecting future demands for some entities that are not specifically evaluated in the draft EIS (i.e., entities that may or may not have CAP allocations presently, and which would not receive a proposed CAP allocation as part of this proposed action.

The demands and water supplies were evaluated for five-year time steps, which were linearly interpolated within the five-year period.

Further details on the analysis methodology are presented in the sub-sections which follow. This includes sub-sections which consider supply and demand for each of the sectors considered (i.e., M&I, Indian, and NIA). The supply and demand for a given sub-area ultimately used in the analysis reflect the sum of the supplies and demands estimated for the M&I, Indian and NIA sectors for that sub-area. Because this analysis is particularly focused on CAP supplies, and because the CAP supplies for each sector are inter-related, a subsection is also included which discusses how CAP water is allocated between the various sectors, and to specific entities under the various pools of available CAP water.

I.B.1. M&I Sector

Fundamental to the use of the hydrologic inventory models was the preparation of a hydrologic inventory and physical water budget for each groundwater sub-area within each model domain. The individual components of the hydrologic inventory and water budget for each sub-area form groundwater pumpage and recharge inputs to the model. Quantifying the water demands and uses by all users for each time step for each sub-area is necessary to develop these primary model inputs. This section of Appendix I discusses the development of the water budget for the M&I portion of each groundwater sub-area within the extent of the five models (Maricopa – Pinal, Chaparral, Cave Creek, Tucson, and Avra). It should be noted that the M&I uses include the M&I entities analyzed in the draft EIS as well as all other municipal water providers that are within the model domains or develop water resources from within the model domains.

In addition, water budgets for M&I uses for each time step, coupled with the timing and use of each M&I users' portfolio of water supplies, provide the basis for assessing the financial impacts of additional costs associated due to development and use of alternative supplies. This section provides the details of developing the water budget and assessment of the timing and use of water supplies used.

The process used to define the water budgets, inputs to the hydrologic inventory models and the use of water supply components may be summarized in the following steps:

- Identify the portfolio of water supplies available to each M&I water provider who is within the model domains or who receives water from within the water model domains;
- Quantify existing M&I water uses, per groundwater sub-area;
- Define the projected water demands per groundwater sub-area and per model time step;
- Apply the water supplies for each M&I user to meet the projected water demands per sub-area and per time step; and
- Calculate groundwater pumping and recharge inputs to the hydrologic inventory models.

The application of water supplies from an M&I user's portfolio of supplies relies on the assumption that M&I water providers would provide the least cost water supply within existing institutional and legal constraints. This assumption generally implies that the last increment of demand would be met by the most expensive water supply. Stated another way, the most costly water supplies are used last. The portfolio of supplies was identified from Assured Water Supply (AWS) applications, ADWR CAP water allocation studies, and water resource master plans.

The inputs to the hydrologic inventory models rely on an assessment of M&I uses and supplies, which is based on available information and assumptions. Taken as a whole, the assessment of M&I uses captures the relative uses and demands for the study to the extent necessary to provide groundwater pumping and recharge inputs to the hydrologic inventory models and assess costs for additional infrastructure. It must be recognized that each individual entity would make unique water supply delivery decisions based on that entity's unique circumstances.

The following sections discuss the steps used to develop the M&I water budgets and the inputs to the hydrologic inventory models.

I.B.1.a. Definition of Portfolio of Supplies

The first step in the analysis is to identify the M&I water providers within the CAP service area to be included in the analysis. GIS spatial database processes were used to determine the geographic extent of each provider's service and planning area within the Phoenix, Pinal and Tucson AMAs that falls within each groundwater sub-area. Each provider was identified using ADWR's GIS database of municipal water providers (ADWR, 1999 cd rom). Some water providers' service or planning areas entirely or partially fall outside of the model domains. Since areas adjacent to but outside the groundwater sub-areas were considered to be poor candidates for groundwater development, it was assumed that absent direct delivery, the provider would develop water resources available from its service area from within the groundwater sub-area. Population projections were based on municipal planning areas (MPAs) for 2000 through 2050 consistent with the projections used by ADWR for water planning.

Once the M&I entities were identified, their available supplies were defined based upon review of each provider's AWS application or certificate of designation, ADWR CAP water allocation studies (ADWR, 03,1999 tables), and provider master plans. The supplies were categorized based on the existing institutional framework. The sources of water included in the water supply portfolio are listed below, in order of decreasing preference of use, based primarily on cost.

- **Salt River Project Water.** Includes surface water as well as groundwater. For the purposes of this analysis, other supplies may be included for surface water irrigation districts such as Roosevelt Water Conservation District (RWCD) and Buckeye Irrigation District (BID).

- **CAP Water.** Original allocations, leases, assignments, and settlement exchanges, and per alternative, reallocated water, and Gila River Indian Community (GRIC) settlement lease.

  - **Original CAP Water.** Original CAP water – Allocated pursuant to the 1983 ROD, including transfers and amendments.
  - **Reallocated CAP Water.** Reallocated CAP water – M&I water reallocated as proposed by ADWR (ADWR, 1999).
  - **Settlement Alternative GRIC Lease.** CAP water provided pursuant to a GRIC water rights settlement that includes the ability to lease CAP water for use outside Reservation lands.

- **Groundwater.** Includes groundwater that ADWR will count toward an AWS, i.e., the phase-in allowance and incidental recharge allowance.

  - **Phase-In Allowance.** ADWR rules allow a small quantity of mined groundwater to be pumped to allow providers time to "phase-in" renewable water supplies. For example, the phase-in allowance for Phoenix AMA providers is calculated by multiplying the entity's 1994 total water demand by 7.5.

- **Incidental Recharge Allowance.** This is calculated as four percent of water uses to account for recharge through the distribution system and residential uses. For this analysis, incidental recharge is held at current levels and is assumed not to increase through time.

♦ **CAP Surface Water.** Includes Salt River Pima-Maricopa Indian Community (SRPMIC) Settlement water, Hohokam Irrigation and Drainage District (HIDD) water, and existing Indian leases.

♦ **Other Surface Water.** Includes gatewater, Roosevelt Conservation Space (RCS), and Wellton-Mohawk water.

♦ **Effluent.** The volume of effluent pledged to meet demands as outlined in AWS designation documents. In the case of the City of Phoenix, additional effluent was assumed to be available to meet water demands and reduce the volume necessary from the Central Arizona Groundwater Replenishment District (CAGRD).

♦ **CAGRD Membership.** Membership in the CAGRD was included as a vehicle to obtain water supply. Several of the entities are currently service area members or have pledged membership to obtain AWS designation. Membership in the CAGRD is assumed to provide the most expensive water supply, and was assumed to meet the last increment of demand after other supplies were used or as specified by existing agreements. In addition it was assumed that the total demand for CAGRD services from the entities could not exceed 200,000 af/year (afa). It was also assumed that the CAGRD members could overcome physical availability limitations by using recent changes in the CAGRD laws that now allow for limited direct delivery of water from CAGRD to members, including recharge and recovery, as well as direct use.

To complete the water balance, a certain quantity of water is recharged for several entities. To determine this amount, the other surface water supplies for all alternatives were held constant at the lowest amount, which occurs under the Settlement Alternative. It is possible, however, that instead of recharging the water not needed for direct use, the entities would directly use the water and correspondingly offset their groundwater pumping. In either case, the incremental impacts would be the same.

The available supplies were evaluated within the framework of the Settlement Alternative, Non-Settlement Alternative 1, Non-Settlement Alternative 2, Non-Settlement Alternative 3, and the No Action Alternative to determine if the municipal water providers' available water supplies were impacted by differences among the alternatives. As is shown in Appendix C, the alternatives result in three water supply scenarios for M&I entities:

♦ Settlement – Approximately 65,647 afa of CAP M&I priority water are allocated to 20 of the 21 M&I entities[1] evaluated in the draft EIS (see Appendix C for summary), and

[1] The ADWR recommended 20 M&I entities to receive a CAP allocation, see Appendix N. If the Town of Superior declines their allocation, then ADWR recommends that allocation to the Arizona Water Company for use in Apache Junction or Superior.

approximately 41,000 afa are made available for long-term leasing from GRIC to M&I users (see Appendix C). Additionally, Mesa and Chandler exchange 40,600 afa of effluent to the GRIC for 32,500 afa of CAP water.

- No Action, Non-Settlement Alternative 2, Non-Settlement Alternative 3A – No additional CAP water supplies are provided.

- Non-Settlement Alternative 1 approximately 65,647 afa of CAP M&I priority water are allocated to 20 of the 21 M&I entities evaluated in the draft EIS.

- Non-Settlement Alternative 3B – approximately 71,815 afa of CAP NIA-priority are allocated to 20 of the 21 M&I entities evaluated in the draft EIS. Being lower priority water than is allocated under the Settlement Alternative or Non-Settlement Alternative 1, it is assumed that the difference between the NIA and M&I priority water (71,815-65,647=6,168 afa) will be recharged to provide firming and the 65,647 afa will be directly used.

From the institutional framework, the water supplies were defined based on hydrologic water source per water supply scenario. The sources of water were aggregated into their respective hydrologic source as either groundwater or surface water. For example, CAGRD as a source is pumped groundwater, although it is replenished with surface water. The water budgets require an understanding of which water supply is pumped or delivered from surface water. The hydrologic sources are defined below:

- Groundwater – includes Salt River Project (SRP) groundwater, phase-in allowance, incidental recharge allowance, and CAGRD uses.

- Surface water – includes SRP surface water, CAP water, effluent, and other surface water.

The water supply portfolio for each water supply scenario was calculated for each M&I water provider within the scope of the study. Water providers with varying water supplies that had different water are described in Appendix C per water supply scenario. The other water providers' water supplies were the same for each of the water supply scenarios. For example, the City of Avondale was not recommended by ADWR to receive an additional allocation and therefore was assumed to have the same water uses across all alternatives.

I.B.1.b. Definition of Projected Water Demands

To develop water budgets for each groundwater sub-area, projected water demands are compared to supplies for each time step during the study period. The projected water demands are prepared based on population projections and assumptions regarding industrial uses within the extent of the hydrologic inventory models.

As discussed in Appendix C, population projections were used to assess the water demands for 2001 through 2051 in five-year time steps. The 1997 DES population projections used by ADWR for water planning purposes served as the basis for population projections. The process used for each water provider not recommended to receive an additional CAP allocation, but within the study area, is similar to the process used for each M&I entity analyzed specifically in the draft EIS, as discussed in Appendix C.

The geographic extent of the population projections was developed from analysis of population planning data developed from TAZ-based population projections from County planning agencies. The population was distributed into the groundwater sub-areas based on the projected growth patterns developed from the analysis of TAZ data.

The general location of population that was projected to fall within existing surface water irrigation districts in the Phoenix AMA was identified for each sub-area. Surface water irrigation districts are those irrigation districts that have extensive water rights to non-CAP surface water sources. Examples include SRP, RWCD, and Buckeye ID.

The population that was identified as occurring within a surface water irrigation district was termed "on-project" population. The on-project population was identified by using GIS spatial database processes to overlay the population projections with the extent of the surface water irrigation districts within each sub-area.

Population within a sub-area that did not fall within a surface water irrigation district was termed "off-project" population. It should be noted that there are no surface water irrigation districts in the Tucson AMA; therefore, all population in the Tucson and Avra models are "off-project."

In addition, population outside of the sub-areas that would be served from water sources within the sub-area was identified. The population that fell outside of the sub-areas was defined as "outside" population. The outside population was identified by a spatial database process that overlaid population with groundwater sub-areas. If population for a provider fell outside of the groundwater sub-area (the assumed limit of groundwater supplies), then the outside population had to rely on direct delivery or water resources provided from the adjacent sub-areas.

The water use rates were developed from the ADWR Third Management Plan (TMP) for the Phoenix and the Tucson AMAs (ADWR, 1999). The water use rates were specified in gallons per capita per day (gpcd) as mandated by the Groundwater Management Act (GMA). The gpcd rates were selected from the final conservation requirement in the management period (2005 – 2010) outlined for M&I providers. For providers not identified in the TMPs, the water use rate or a provider in an adjacent area with similar residential and turf characteristics was used. The gpcd rates used for this analysis include a seven-percent increase to accommodate lost and unaccounted-for water. Lost and unaccounted-for water includes leaks, spills, and flows too low to meter. The seven- percent increase was derived from a review of several water providers including Peoria, Scottsdale, and Phoenix. Lost and unaccounted-for water is typically between five and ten percent of total water use.

The projected water demands were calculated by multiplying the projected population by the water use rate (gpcd) and converting to afa. The issues and assumptions relevant to the gpcd water use rates are discussed in detail in Appendix C.

The water use rates were used to calculate the water demands per M&I provider per groundwater sub-area per time period. The same water demand rates were applied for populations "on-project," "off-project," and "outside" within each groundwater sub-area.

In addition to the M&I provider demands, a review of the TMPs showed that many groundwater sub-areas had industrial uses not captured using the population-based gpcd method. A review of the TMP data showed that industrial demands are approximately 10 percent of the total M&I provider demands. It is assumed for the purposes of the draft EIS that industrial demands are distributed equally across all groundwater sub-areas that include M&I provider demands at a rate of 10 percent of the provider demands in each sub-area.

In the Cave Creek area, industrial demands were adjusted to reflect the six golf courses within this sub-area. Each golf course was assumed to cover 90 acres with a five-af per acre demand. The additional industrial demand was met with CAP water and effluent until the M&I demands completely use Cave Creek's CAP allocation. As this point, the additional industrial demand is met by effluent.

In the Green Valley central sub-area, an additional industrial demand was added to account for the Cyprus Sierita Mine. This constant demand (26,000 af) was met entirely by groundwater pumping. Another mine was added to the San Xavier east sub-area to account for the ASARCO Mission Mine. Again, the constant demand (13,000 af) was met entirely by groundwater pumping.

In recognition of the water demands for surface water to irrigate residential landscape within portions of the SRP service area in the Phoenix AMA, urban irrigation was included. Urban irrigation demand is assumed to be approximately 140,000 af (Phoenix AMA TMP, 1999). It is assumed that the urban irrigation is spread evenly over 10 SRP dominated sub-areas.

Tables were developed which summarize the total water demands for each groundwater sub-area for each water supply scenario, Table I-1, which shows that information for the Chandler South sub-area for the Settlement Alternative, is provided as a sample of those tables.

I.B.1.c. Assign Supplies to Meet Demands

The water supply from each M&I provider was assigned to meet water demands projected for each provider in each sub-area per time step. The application of supplies was based on assumed least cost supply. The assumption is that the M&I providers will use their least costly supplies first with the last increment of demand met from the most costly supplies. The assignment of supplies to meet demands is based on the following assumptions:

- Surface water irrigation district supplies are available to meet all "on-project" demands. The water supply and demands fall primarily upon SRP lands or other surface water irrigation district lands such as RWCD, Roosevelt Irrigation District (RID), BID, or Maricopa Water District (MWD).

- Off Project demands are met from the following in order of use:

    - Groundwater phase-in allowance
    - Groundwater incidental recharge allowance
    - CAP water
    - Other surface supplies including effluent
    - CAGRD supplies.

- Outside demands are met by the same priority as off-project demands.

- In the Tucson and Avra models, on-project demands do not exist.

    - CAP water is "phased-in" within the first five-year period of the study. During this period, M&I entities gradually increase the amount of CAP water used and equally decrease the amount of groundwater to meet their demands.

    - The Tucson and Avra Valley M&I entities utilize "put and take" recharge and recovery facilities to use their CAP water. This involves recharging their CAP water in recharge facilities such as the Avra Valley Recharge Project, Central Avra Valley Storage and Recovery Project (CAVSARP), Pima Mine Road Recharge Project and the Santa Cruz Managed Recharge Project. The M&I entities use wells to "recover" their CAP water with a 5 percent "cut to the aquifer" requirement. This "recovery" occurs within the Cortaro-Marana Irrigation District (CMID) East, Metropolitian Domestic Water Improvement District (MDWID), Tucson West, and Tucson East sub-areas of the groundwater model.

    - The City of Tucson is assumed to use CAGRD water prior to using effluent because the City is under contract for 12,500 afa of CAGRD obligation after 2005.

    - The City of Tucson has pledged to build a well field to provide groundwater from Avra Valley to the City. The groundwater model begins utilizing this facility in 2017 as an additional place to "recover" CAP water.

- Industrial demands are met by:

    - Groundwater equal to 85 percent of the 2001 demand with groundwater pumping held constant moving forward in time.

    - Effluent meets 15 percent of the 2001 demand and meets the incremental increase in industrial demands moving forward from 2001.

    - CAP water and effluent for the Cave Creek model of additional industrial demand (golf courses). CAP water is used until the M&I demands equal the CAP allocation. For the Settlement Alternative and Non-Settlement Alternatives 1 and 3B, this occurs in 2026. For the No-Action Alternative and Non-Settlement Alternatives 2 and 3A, this occurs in 2016. At this point, the additional industrial demands are met entirely by effluent.

- Groundwater for the San Xavier East and the Green Valley Central sub-areas of the Tucson groundwater model for additional industrial/mining demands.

The total water demands and the supplies used to meet those demands are summarized for each groundwater sub-area for each water supply scenario per time step. As shown on the sample presented in Table I-1, the tables summarize the water supplies from the standpoint of hydrologic source and institutional source.

- ♦ CAP Water – Includes all types of CAP water including:
    - No Action and All Alternatives
    - Original Allocation
    - Assignments, existing settlements, leases and exchanges
    - Settlement Alternative - Reallocated and GRIC lease water in addition to the No Action Alternative supplies
    - Non-Settlement Alternative 1 and 3B - Reallocated water in addition to the No Action supplies
- ♦ Municipal Groundwater - Groundwater including:
    - Phase-In Allowance
    - Incidental Recharge Allowance
- ♦ Industrial Groundwater - Other groundwater pumped for industrial uses
- ♦ Municipal Effluent - Recharge and recovered effluent or direct use of effluent
- ♦ Industrial Effluent - Direct use of effluent for industrial uses including turf (for example, parks and golf courses)
- ♦ Other Surface Water
- ♦ CAGRD Membership
- ♦ SRP water - Includes other surface water irrigation district demands.
    - Surface water is 70 percent of supply.
    - Groundwater is 30 percent of supply.
    - Includes urban irrigation demands as well as residential demands.

These categories were developed to capture the hydrologic components of the water supply within the context of the institutional constraints of water uses provided by current water use laws and policies.

I.B.1.d. Calculate Input to Hydrologic Inventory

Water budgets were calculated from the detailed analysis of the temporal and spatial distribution of water uses and supplies, as illustrated on the sample presented in Table I-1. From the water budgets, two inputs were provided to the hydrologic inventory models. The inputs are groundwater pumping and groundwater recharge. These inputs to the hydrologic inventory models were calculated from the water budgets for each groundwater sub-area per time period, as discussed in the following sub-sections:

I.B.1.d.(1). Groundwater Pumpage

Groundwater pumpage was calculated as the sum of:

- SRP groundwater
- Municipal groundwater
- Industrial groundwater
- Pumping during shortage conditions (2044 – 2051)

Groundwater pumpage is increased for sub-areas in the Phoenix area by the volume of CAP shortage, to simulate recovery of Arizona Water Banking Authority (AWBA) credits. No recovery occurs in the Tucson area.

I.B.1.d.(2). Groundwater Recharge

Groundwater recharge was calculated as the sum of:

- **Four percent of total municipal uses** to account for assumed four percent of system losses due to distribution, residential, non-residential and losses.

- **Twelve percent of total industrial uses** to account for recharge associated with turf and other facilities.

- **One hundred percent of direct recharge** located within any sub-area.

- **Twenty-four percent of urban irrigation** based on ADWR TMP for Phoenix AMA.

I.B.1.e. Analysis of Process

The inputs to the hydrologic inventory models derived from the foregoing analysis may be sensitive in the areas discussed in the following sub-sections.

I.B.1.e.(1) Assumed Water Demand Rates

If the water demand rates are significantly higher in the future than required by State law in the TMP, the volume of groundwater pumping would likely increase as a result of increased membership in the CAGRD. The discussion in Appendix C illustrates historic water use trends. With the exception of areas that include large non-residential uses or low persons per household, water use rates are moving toward the TMP requirements.

I.B.1.e.(2). Location of Water Demands

The physical location of demands relative to "on-" vs. "off- project" may impact the inputs to the hydrologic inventory models. For example, if the population off-project is underestimated (conversely, if on-project is overestimated), groundwater pumping may be overstated because 30 percent of the demands for on-project use are assumed to be met by groundwater. In addition, it may be that the location of on-project pumping varies from the assumed even spread across the sub-areas. The assumption of even spread may tend to underestimate groundwater pumping in sub-areas that have concentrated pumping while overstating the impacts in other areas.

I.B.1.e.(3). Assumption Regarding the Deployment of Water Supplies

The assumption used may show an accelerated use of CAP supplies relative to current projections. It is assumed that water providers would develop facilities to meet the demands as soon as the demands appear. That is to say, as soon as additional population and, thus, demands appear, the infrastructure is in place to meet the demands. There is no assumed lag time for new facilities. It appears that the ongoing planning activities such as the WESTCAPS process seem to support an accelerated use of CAP supplies. In the Tucson area, it is assumed that the entities would take CAP water as soon as the water becomes available. To do this requires "put and take" recharge and recovery facilities, also termed "annual storage and recovery facilities." The facilities do not require use of additional treatment plants. These facilities are either under construction or are in place for Tucson and other providers in the area. It appears that this assumption is consistent with current planned water use and policy in the Tucson area, although full use of CAP supplies starting in year 2001 may prove to be an overly optimistic assumption.

I.B.1.e.(4). Effluent Recharge and Use

Effluent is used to the extent that entities have pledged their supplies for AWS purposes. Additional effluent is used to satisfy industrial uses including golf courses. The effluent that may be available for local recharge is assumed to be disposed of in the current manner at regional wastewater treatment plants. It appears that the effluent water supplies available to those treatment plants would remain at least at current levels, if not increase through time.

I.B.1.e.(5). Water Supplies for Shortage Conditions

It is assumed that CAP shortages would be met by AWBA recovery programs that would pump groundwater from the Phoenix AMA and deliver full CAP supplies to the Tucson area. This assumes that M&I entities in the Phoenix AMA use existing wells and have sufficient capacity to meet current demands and shortage demands. During shortage, the calculation of groundwater pumpage is increased by the amount of CAP shortage. This pumpage would be the recovery of stored AWBA groundwater credits and is spread equally among ten sub-areas in the Salt River Valley portion of the model.

I.B.2. Indian Sector

Methodology and assumptions used to estimate inputs to the groundwater analysis for Indian entities are discussed in this section. The sub-sections, which follow, provide discussion for the GRIC, the Tohono O'odham Nation (TON) (including the Schuk Toak and San Xavier Districts), and the SC Apache Tribe. The Navajo Nation and Hopi Tribe were evaluated using a more qualitative analysis, and so are not included in this section. All of the Indian entities have high priority CAP water supplies, so that the full supplies shown in the water budgets for each alternative are assumed to be available in almost all years.

I.B.2.a. GRIC

Based on the hypothetical non-binding plans to take water discussed in Appendix L, water budgets were developed for GRIC under each of the alternatives. These water budgets take into account existing water development plans, analysis of existing contracts and agreements, and data provided from Reclamation staff. All of the alternatives assume a five-percent diversion loss and an on-farm efficiency of 78 percent, which reflects improvements in the GRIC distribution system as described in the PMIP PEIS. An overall groundwater pumping limit was imposed at 157,000 afa for all alternatives. The GRIC is located within six groundwater model sub-areas of the Pinal and Salt River Valley groundwater model. The total amount of farmed acreage was equally distributed among these six sub-areas to provide inputs to the groundwater model. Under shortage conditions, beginning in the year 2044, the GRIC does not receive their NIA priority water. To simulate the shortage in the groundwater model, acreage was fallowed and/or supplemental groundwater pumping was allowed to occur.

I.B.2.a.(1). Settlement Alternative

The water budget for the Settlement Alternative is presented in Table I-2.

Table I-2
Gila River Indian Community
Water Budget
Settlement Alternative

Source	Quantity (afa)
Groundwater	157,000
Original CAP Allocation	173,100
Globe Equity Decree	125,000
Haggard Decree	5,900
RWCD CAP	18,600
RWCD	4,500
Harquahala Valley Irrigation District (HVID) CAP	17,800
ASARCO	17,000
SRP	20,000
Chandler Reclaimed Water	4,500
Net Reclaimed Water Exchange	8,100
New CAP Allocation	102,000
Total Settlement Budget	653,500
Water for Agriculture	531,000

Of the 653,500 afa total settlement water budget, 102,500 afa would be leased or exchanged for off-Reservation use, and 20,000 afa would be used on-Reservation for M&I purposes, leaving 531,000 afa for on-Reservation agricultural use.

For the Settlement Alternative, a total of about 118,000 acres could be farmed with the 531,000 af of water for agriculture using a water duty of 4.5 af per acre. A linear build-out schedule of the water supplies is followed for the GRIC starting in the year 2005 and reaching complete build-out by 2020. During shortage conditions, 33,191 acres are temporarily fallowed due to the GRIC not receiving 149,359 afa of NIA priority water.

I.B.2.a.(2). No Action Alternative

The water budget for the No Action Alternative is presented in Table I-3.

Table I-3
Gila River Indian Community
Water Budget
No Action Alternative

Source	Quantity (afa)
Groundwater	80,000
Original CAP Allocation	173,100
Globe Equity Decree	125,000
Haggard Decree	5,900
RWCD	4,500
SRP	13,104
Chandler Reclaimed Water	4,500
Total No Action Alternative	406,104

For the No Action Alternative, a total of about 85,800 acres could be farmed with the 386,104 af of water for agriculture using a water duty of 4.5 af per acre. The other 20,000 afa is used for GRIC M&I purposes, and no off-Reservation leases would occur. A linear build-out schedule of the water supplies is followed for the GRIC, starting in the year 2005 and reaching complete build-out by 2020. The schedule utilizes all of the water sources available to the Tribe. For the No Action Alternative, groundwater pumping starts at 40,000 af in the year 2005 and linearly increases to 80,000 af in the year 2020, at which level it continues for the study period duration. Shortage conditions do not affect CAP water deliveries in the No Action Alternative.

I.B.2.a.(3). Non-Settlement Alternative 1

The water budget for the Non-Settlement Alternative 1 is presented in Table I-4.

Table I-4
Gila River Indian Community
Water Budget
Non-Settlement Alternative 1

Source	Quantity (afa)
Groundwater	80,000
Original CAP Allocation	173,100
Globe Equity Decree	125,000
Haggard Decree	5,900
RWCD CAP	18,600
RWCD	4,500
HVID CAP	17,800*
ASARCO	17,000
SRP	13,104
Chandler Reclaimed Water	4,500
Total Non-Settlement Alternative 1 Budget	459,504

* Water reserved for future final water rights settlement consistent with Fort McDowell Indian Water Rights Settlement Act Provisions.

Under Non-Settlement Alternative 1, 17,800 afa are designated but not allocated (or used), 20,000 afa are used for GRIC M&I purposes, and no off-Reservation leases occur, so 421,704 afa are available for on-Reservation agricultural purposes. A total of 93,700 acres could be farmed with the 421,704 af of water for agriculture using a water duty of 4.5 af per acre. A linear build-out schedule of the water supplies is followed for the GRIC, starting in the year 2005 and reaching complete build-out by 2020. The schedule utilizes all of the water sources available to the Tribe. For the Non-Settlement Alternative 1, groundwater pumping starts at 40,000 af in the year 2005 and linearly increases to 80,000 af in the year 2020. It continues at that level for the study period duration. During shortage conditions, groundwater pumping increases by 18,600 afa due to the GRIC not receiving NIA priority water.

I.B.2.a.(4). Non-Settlement Alternative 2

The water budget for the Non-Settlement Alternative 2 is shown in Table I-5.

Table I-5
Gila River Indian Community
Water Budget
Non-Settlement Alternative 2

Source	Quantity (afa)
Groundwater	80,000
Original CAP Allocation	173,100
Globe Equity Decree	125,000
Haggard Decree	5,900
RWCD CAP	18,600
RWCD	4,500
HVID CAP	17,800*
ASARCO	17,000
SRP	13,104
Chandler Reclaimed Water	4,500
New CAP Allocation	34,499
Total Non-Settlement Budget	499,003

* Water reserved for future final water rights settlement consistent with Fort McDowell Indian Water Rights Settlement Act provisions.

Under Non-Settlement Alternative 2, 17,800 afa are designated but not allocated (or used), 20,000 afa are used for GRIC M&I purposes, and no off-Reservation leases occur, so 461,203 afa are available for on-Reservation agricultural purposes. A total of 102,500 acres could be farmed with the 461,203 af of water for agriculture using a water duty of 4.5 af per acre. A linear build-out schedule of the water supplies is followed for the GRIC, starting in the year 2005 and reaching complete build-out by 2020. The schedule utilizes all of the water sources available to the Tribe. For the Non-Settlement Alternative 2, groundwater pumping starts at 40,000 af in the year 2005 and linearly increases to 80,000 af in the year 2020. It continues at that level for the study period duration. During shortage conditions, groundwater pumping increases by 54,440 afa due to the GRIC not receiving NIA priority water.

I.B.2.a.(5). Non-Settlement Alternative 3

The water budget for the Non-Settlement Alternative 3 is shown in Table I-6.

Table I-6
Gila River Indian Community
Water Budget
Non-Settlement Alternative 3

Source	**Quantity (afa)**
Groundwater	139,396
Original CAP Allocation	173,100
Globe Equity Decree	125,000
Haggard Decree	5,900
RWCD CAP	18,600
RWCD	4,500
HVID CAP	17,800*
ASARCO	17,000
SRP	13,104
Chandler Reclaimed Water	4,500
New CAP Allocation	134,600
Total Non-Settlement Budget	653,500

* Water reserved for future final water rights settlement consistent with Fort McDowell Indian Water Rights Settlement Act provisions.

For the Non-Settlement Alternative 3, 17,800 afa are designated but not allocated (or used), 20,000 afa are used for GRIC M&I purposes, and no off-Reservation leases occur, so 615,700 afa are available for on-Reservation agricultural purposes. A total of 136,800 acres could be farmed with the 615,700 af of water for agriculture using a water duty of 4.5 af per acre. A linear build-out schedule of the water supplies is followed for the GRIC, starting in the year 2005 and reaching complete build-out by 2020. The schedule utilizes all of the water sources available to the Tribe. Groundwater pumping starts at 40,000 afa in the year 2005 and linearly increases to 139,396 afa in the year 2020. It continues at that level for the study period duration. During shortage conditions, groundwater pumping increases by 17,604 afa and 29,319 acres are temporarily fallowed due to the GRIC not receiving 149,541 afa of NIA priority water.

I.B.2.b. TON

The TON includes the Schuk Toak and San Xavier Districts. Inputs to the groundwater analysis were developed separately for these districts, as described in the following sub-sections.

I.B.2.b.(1). Schuk Toak District

Based on the hypothetical non-binding plans to take water described in Appendix L, water budgets were developed for each of the alternatives. These water budgets take into account existing water development plans, analysis of existing contracts and agreements, and data provided from Reclamation staff. All of the alternatives assume a water duty of 5.0 af per acre and an irrigation efficiency of 76 percent. The total amount of farmed acreage was placed within the South Avra Valley sub-area (discussed later) to provide inputs to the groundwater model.

The water budget for the Settlement Alternative and Non-Settlement Alternatives 2 and 3 is shown in Table I-7.

Table I-7
Tohono O'odham Nation, Schuk Toak District
Water Budget
Settlement Alternative and
Non-Settlement Alternatives 2 and 3

Source	Quantity (afa)
Original CAP Allocation	10,800
New CAP Allocation	5,200
Total Water Budget	16,000

All CAP water is assumed to be used for agricultural purposes.

A total of about 3,200 acres could be farmed under these alternatives using a water duty of 5.0 af per acre. It was assumed that the Schuk Toak District would take a portion of their original CAP allocation in 2001 and take the complete allocation within a year. For the new CAP allocation, the Schuk Toak District would take a portion of the new CAP allocation in 2005 and take the complete new allocation within a year. No significant groundwater pumping is assumed to occur.

The water budget for the No Action Alternative and Non-Settlement Alternative 1 is shown in Table I-8.

Table I-8
Tohono O'odham Nation, Schuk Toak District
Water Budget
No Action Alternative and Non-Settlement Alternative 1

Source	Quantity (afa)
Original CAP Allocation	10,800
New CAP Allocation	0
Total Water Budget	10,800

All CAP water is assumed to be used for agricultural purposes.

A total of about 2,200 acres could be farmed under these alternatives using a water duty of 5.0 af per acre. It was assumed that the Schuk Toak District would take a portion of their original CAP allocation in 2001 and take the complete allocation within a year. No significant groundwater pumping is assumed to occur.

I.B.2.b.(2). San Xavier District

Based on the hypothetical non-binding plans to take water, discussed in Appendix L, water budgets were developed for the San Xavier District under each of the alternatives. These water budgets take into account existing water development plans, analysis of existing contracts and agreements, and data provided from Reclamation staff. All of the alternatives assume a water duty of 5.0 af per acre and an irrigation efficiency of 76 percent. The total amount of farmed acreage was placed within the San Xavier East sub-area of the Tucson groundwater analysis.

The water budget for the Settlement Alternative, and Non-Settlement Alternatives 2 and 3 is shown in Table I-9.

Table I-9
Tohono O'odham Nation, San Xavier District
Water Budget
Settlement Alternative and Non-Settlement Alternatives 2 and 3

Source	Quantity (afa)
Original CAP Allocation	27,000
New CAP Allocation	23,000
Total Water Budget	50,000

Of the 50,000 afa, 8,000 afa would be used for direct groundwater recharge, leaving 42,000 afa for on-Reservation agricultural use.

A total of about 8,400 acres could be farmed with the 42,000 af of water for agriculture using a water duty of 5.0 af per acre. A build-out schedule for the original CAP allocation is followed for the San Xavier District that starts in 2001 and reaches complete build-out in 2012. The new CAP allocation would follow a build-out schedule that starts in 2015 and is completed within five years. No significant groundwater pumping is assumed to occur.

The water budget for Non-Settlement Alternative 1 is shown in Table I-10.

Table I-10
Tohono O'odham Nation, San Xavier District
Water Budget
No Action Alternative and Non-Settlement Alternative 1

Source	Quantity (afa)
Original CAP Allocation	27,000
Total Water Budget	27,000

All of the 27,000 afa would be used for on-Reservation agricultural purposes.

A total of about 5,400 acres could be farmed with the 27,000 af of water for agriculture using a water duty of 5.0 af per acre. A build-out schedule for the original CAP allocation is followed for the San Xavier District that starts in 2001 and reaches complete build-out in 2012. No significant groundwater pumping is assumed to occur.

I.B.2.c. SC Apache Tribe

Based on the hypothetical non-binding plans to take water discussed in Appendix L, water budgets were developed for each of the alternatives. These water budgets take into account existing water development plans, analysis of existing contracts and agreements, and data provided from Reclamation staff. All of the alternatives assume a water duty of 5.0 af per acre for the CAP allocations, and a water duty of 6.0 af per acre is assumed for the Globe Equity Decree. The SC Apache Tribe lands are located within a separate groundwater study area (discussed later).

The water budget for the Settlement Alternative, No Action Alternative, and Non-Settlement Alternative 1 is shown in Table I-11.

Table I-11
SC Apache Tribe
Water Budget
Settlement Alternative, No Action Alternative, and Non-Settlement Alternative 1

Source	Quantity (afa)
Original CAP Allocation	61,645
Globe Equity Decree	6,000
Total Water Budget	67,645

Of the 67,645 afa total water budget, 29,980 afa are leased for off-Reservation use (see Appendix A), leaving 37,665 afa for on-Reservation agricultural purposes.

A total of about 7,300 acres could be farmed with the 37,665 af of water for agriculture. A total of about 6,300 acres could be farmed using the CAP allocation and associated water duty, and an additional 1,000 acres could be farmed using the Globe Equity Decree water duty. The build-out schedule for the original CAP allocation starts in 2005 and reaches complete build-out in 2010.

The water budget for the Non-Settlement Alternative 2 is shown in Table I-12.

Table I-12
SC Apache Tribe
Water Budget
Non-Settlement Alternative 2

Source	Quantity (afa)
Original CAP Allocation	61,645
Globe Equity Decree	6,000
New CAP Allocation	23,447
Total Water Budget	91,092

Of the 91,092 afa total water budget, 29,980 afa are leased for off-Reservation use (see Appendix A), leaving 61,112 afa for on-Reservation agricultural purposes.

A total of about 12,000 acres could be farmed with the 61,112 af of water for agriculture using a water duty of 5.0 af per acre. A total of 11,000 acres could be farmed using the CAP allocation and associated water duty, and an additional 1,000 acres could be farmed using the Globe Equity Decree water duty. The build-out schedule for the original CAP allocation starts in 2005 and reaches complete build-out in 2010. The new CAP allocation would follow the same build-out as the original CAP allocation.

The water budget for Non-Settlement Alternative 3 is shown in Table I-13.

Table I-13
SC Apache Tribe
Water Budget
Non-Settlement Alternative 3

Source	Quantity (afa)
Original CAP Allocation	61,645
Globe Equity Decree	6,000
New CAP Allocation	40,000
Total Water Budget	107,645

Of the 107,645 afa total water budget, 29980 afa are leased for off-Reservation use (see Appendix A), leaving 77,665 afa for on-Reservation agricultural purposes.

A total of about 15,300 acres could be farmed with the 77,665 af of water for agriculture using a water duty of 5.0 af per acre. A total of 14,300 acres could be farmed using the CAP allocation and associated water duty, and an additional 1,000 acres could be farmed using the Globe Equity Decree water duty. The build-out schedule for the original CAP allocation starts in 2005 and reaches complete build-out in 2010. The new CAP allocation would follow the same build-out as the original CAP allocation.

I.B.3. NIA Sector

The groundwater pumping and recharge components of the hydrologic inventory analyses include inputs attributable to NIA. This section discusses how these inputs were estimated for the evaluation of the alternatives. Spreadsheets were developed to implement the process discussed herein.

I.B.3.a. Groundwater Pumping for NIA

The basic process used to estimate groundwater pumping is:

- Estimate irrigated acres, broken down by district, for each sub-area or analysis area;
- Estimate the applied water requirement for the irrigated lands;
- Estimate the surface water supplies available to meet irrigation demands, and
- Compute the groundwater pumping as the applied water requirements in excess of the available surface water supplies.

- ♦ Groundwater pumping schedule evaluated in socioeconomic model to determine economic feasibility and be adjusted, if necessary.

Characteristics of agricultural districts used to estimate groundwater pumping are summarized in Table I-14.

I.B.3.b. Irrigated Acres

Irrigated acres were estimated by several means. The acres were estimated as described in the discussion of the socio-economic analysis for Central Arizona Irrigation and Drainage District (CAIDD), HIDD, New Magma Irrigation and Drainage District (NMIDD), Maricopa-Stanfield Irrigation & Drainage District (MSIDD), QCID and TID. The irrigated acres for these entities can vary over time under each alternative. For other entities, the acreage was estimated based on the grandfathered groundwater rights lands in those entities. This includes some entities which may receive CAP water from the Ag Pool under some alternatives (San Carlos Irrigation & Drainage District (SCIDD), San Tan Irrigation District (STID), and CHCID).

The potential for urbanization was also considered in defining the irrigated acres. This evaluation was based on consideration of projected population changes in sub-areas that presently include irrigated agriculture, number of persons per household, and households per acre based on local development patterns. The relationship between sub-area boundaries to county census divisions was used to estimate how much of the impact for a given county census division would apply to a particular sub-area.

The agricultural acreage within each sub-area was identified by comparison of boundaries for each district with the sub-area boundaries. The amount of irrigated acres within each sub-area was assumed to be proportional to the total district acreage in the sub-area.

I.B.3.c. Applied Water Requirements

Applied water requirements were estimated by several different means in this analysis. For those districts which may receive CAP water under some of the alternatives (i.e., CAIDD, HHID, NMIDD, MSIDD, QCID, TID, SCIDD, STID, CHCID), the applied water requirements (and the acreage which would be irrigated) were estimated as described in the discussion of the socio-economic analysis.

There are also irrigated lands within the analysis areas for entities which will not receive CAP allocations under any of the alternatives. Where available, information from the TMP for the AMAs were used to define the cropping pattern and the weighted average consumptive use. Those data are summarized in Table I-14 from the Phoenix and Tucson AMAs. The weighted average consumptive use estimated from data for the Phoenix AMA (3.19 af per acre) appears to be low, and for the purpose of this analysis, a weighted average consumptive use of 3.43 af per acre has been used.

The applied water requirements were then estimated by dividing the consumptive use by the irrigation efficiency. For both the Tucson and Phoenix AMAs, the TMP indicates an irrigation efficiency of 76 percent, which has been used in this analysis.

I.B.3.d. Surface Water Supplies

Surface water supplies include CAP water and surface water available from other sources. The non-CAP water was generally estimated with reference to the Water Service Organizations book, prepared by ADWR. For the purpose of this analysis, the identified surface water supplies were assumed to be available in every year, and the values are shown in Table I-14.

The availability of CAP water depends on the availability and distribution of water from the Ag Pool and the Recharge Pool. The evaluation of the operation of these pools is based on the background assumptions presented in Appendix A. The details on the evaluation of CAP supplies are presented in Section I.B.4. which addresses CAP water supplies.

I.B.3.e. Groundwater Supplies

Groundwater supplies are assumed to meet applied water requirements in excess of surface water supplies.

I.B.3.f. Incidental Recharge from NIA

A portion of the irrigation applications in excess of the crop consumptive use requirements can percolate and provide recharge to groundwater. Assumptions used to estimate the incidental recharge were developed from the TMP for the AMAs where available. In other areas, assumptions were made to estimate the incidental recharge reflecting estimated irrigation efficiencies.

For irrigated lands in the Phoenix, Pinal, and Tucson AMAs incidental recharge was generally estimated to be 24 percent of the total applied water. An exception is that incidental recharge is estimated to be 28 percent for SCIDD, reflecting the relatively high seepage losses which have historically occurred in the unlined canals of this district. Under Alternative 3A, these canals are assumed to be lined, and a 24 percent incidental recharge is assumed for SCIDD.

Pageholder for Table (Diane Hanna has file) k:\cap_eis\scp\NIA inputs table

I.B.4. CAP Water Supplies

CAP water is supplied to each of the sectors considered in this analysis (M&I, Indian, and NIA). While in general, separate discussion is provided for each sector, the amount of CAP water for each sector depends in part on the amounts of CAP water available for the other sectors. Therefore, this section discusses how available CAP water was distributed to each sector. Appendix A contains a comprehensive discussion of CAP water distribution to contractors, subcontractors, and pools.

The overall availability of CAP water for this analysis was assumed to be 1,415,000 afa delivered from 2001 to 2043. This represents normal CAP deliveries. From 2044 to 2051, it is assumed that there would be shortages, with a total CAP supply available of 925,000 afa delivered.

I.B.4.a. Distribution of CAP Water Supplies by Sector

M&I and Indian contractors would have allocations for CAP water, which would vary for the various alternatives considered. Indian contractors and M&I sub-contractors have the combined highest priority of CAP water. After their contracted deliveries are satisfied, the remaining water (termed "Excess Water") is available for several different pools. Water from these pools is made available for groundwater recharge and for agricultural use, as discussed below.

I.B.4.b. Methodology for Distributing the Ag and Recharge Pools

Excess Water is placed into an Ag Pool (available for irrigation uses) and a Recharge Pool (available for both direct and in-lieu recharge uses for both M&I and NIA entities). The Recharge Pool includes Excess Water used by CAGRD for recharge in certain of the direct recharge facilities. Appendix A contains a thorough discussion of the distribution of water into the Ag and Recharge Pools. The following discussion focuses on the distribution of water out of those pools to individual entities.

Under the Settlement Alternative, the Ag Pool water is distributed to NIA entities based on CAWCD's March 30, 2000 memorandum, "Discussion of Excess Water Marketing for Non-Indian Agricultural and Other Uses." Under the Non-Settlement Alternatives, the Ag Pool water is distributed to NIA entities based on an evaluation of NIA percentages published by Central Arizona Water Conservation District (CAWCD).

Initially, the Ag Pool is further broken down into three sub-pools. The water from the sub-pools is distributed between the various entities as discussed above; however, the costs vary for each of the sub-pools. Based on the July 8, 1999 CAWCD memorandum, "Calendar Year 2000 Central Arizona Project Water Rates," there are three Ag Pools from 2001 to 2003. Ag Pools One and Two are set at 200,000 af each, while any additional water available to the Ag Pools is distributed to Ag Pool Three. For example, the Settlement Alternative has a total of 550,000 af available to the Ag Pools in 2001. Ag Pool One and Two would each have 200,000 af and Ag Pool Three would have 150,000 af. After 2003, there is assumed to be a single Ag Pool.

Tables were prepared to show the distribution of Ag Pool water to the various entities. For years 2001, 2002, and 2003, the Ag Pool was broken down by Ag Sub-pool and tables were prepared for each alternative. Sample tabulations are presented in Table I-15 for the No Action Alternative and in Table I-16 for the Settlement Alternative. Similar tables were prepared for years 2004 to 2051 for each alternative, and sample tabulations are presented in Table I-17 for the No Action Alternative and in Table I-18 for the Settlement Alternative.

Figure I-2 illustrates the methodology for distributing the Recharge Pool water between direct and in-lieu recharge. It is anticipated that the CAWCD would make water available and AWBA would continue to provide recharge water through its in-lieu program through 2016. The direct and in-lieu amounts are consistent with current recharge volumes and current AWBA policy, as outlined in their Annual Report for 2000 (see Table A-2). After 2016, the funding for the AWBA would sunset. At this point, it is assumed that M&I entities would continue to recharge directly, and in lieu with nearby agricultural entities.

The CAGRD water, which is included in the Recharge Pool, was split among the East and West Salt River Valley members and Tucson area members. The East Salt River Valley members include H2O Water Company, Chaparral Water Company, Apache Junction, Cave Creek, Mesa, Chandler, Scottsdale, and Superior. The West Salt River Valley members include Peoria, Glendale, Surprise, El Mirage, Phoenix, Goodyear, and Valley Utilities. The Tucson members include Oro Valley, MDWID, Tucson, Avra Coop, Green Valley, and Del Lago. The CAGRD pool includes CAP water necessary to meet the projected replenishment obligation of existing CAGRD members of the CAP EIS M&I entities. It is assumed that M&I entities who were not identified by ADWR for allocation of CAP water would not require additional CAGRD supplies.

The distribution of CAGRD recharge demands has been split between East Salt River Valley, West Salt River Valley, and Tucson area based on the location of the M&I entities' replenishment demands. The split shows where CAGRD would likely replenish (recharge) CAP water over the study period. The split is based on a review of the CAGRD demands for each entity over the period (Appendix C) and the location of the entity relative to the East Salt River Valley, West Salt River Valley, and Tucson AMA boundaries.

The Recharge Pool was broken down into direct facilities and in-lieu facilities. If the available Recharge Pool is greater than the total capacity of all the direct facilities for the period of 2001 to 2016, the facilities receive their full amounts. The remaining Recharge Pool is then distributed to the in-lieu facilities.

The distribution of water from the Recharge Pool for in-lieu recharge is illustrated on Figure I-3. The Pinal County in-lieu facilities (CAIDD, HIDD, and MSIDD) are held at constant capacities as set in the AWBA 2000 Plan of Operation until 2017, when they no longer receive in-lieu water. The remaining in-lieu facilities are NMIDD, Queen Creek Irrigation District (QCID), Chandler Heights Citrus Irrigation District (CHCID), TID, MWD, RWCD, SRP, Kai Farms (KAI), CMID, and Bing K. Wong Farms (BKW). If the remaining Recharge Pool (after direct facilities are full) exceeds the total capacity of the remaining in-lieu facilities, it is distributed to the in-lieu facilities in direct proportion to their 1998 actual deliveries (i.e., the recharge is constrained to remain within the 1998 actual deliveries). Any remaining water in the Recharge

Pool is then distributed to SRP's in-lieu facility. SRP was chosen as the recipient of additional in-lieu water because it already has a substantial surface water supply and would be least likely to skew the groundwater impacts analysis. The AWBA and M&I entities have a total of 200,000 afa of Groundwater Savings Facility permits for SRP. If the remaining pool is less than the total capacity of the in-lieu facilities, it is distributed to all of the facilities in direct proportion to their 1998 actual deliveries.

If the available Recharge Pool is less than the total capacity of all the direct facilities, the facilities receive an amount in direct proportion to their share of the total overall direct capacity, and no amount would be available to the in-lieu facilities.

I.C. Methodology to Evaluate Water Quality Impacts

The quality of groundwater is a factor in the suitability of the groundwater supply for irrigation, municipal, and industrial uses. Changes in groundwater quality related to the proposed CAP allocations could, therefore, have a significant impact on the use of those supplies.

The potential for water quality impacts was evaluated on a qualitative basis. The CAP reallocation could impact groundwater quality through the following three basic mechanisms:

- Changes in the flow pattern could induce or retard the lateral movement of poor quality water to wells;
- Lowering of groundwater levels could result in production of water from deeper aquifer zones containing poor quality water; and
- Direct recharge of CAP water could impact the quality of groundwater in the aquifer receiving recharge.

Methodology to identify impacts associated with these three potential impact mechanisms are discussed in the sub-sections which follow.

I.C.1. Lateral Movement

Evaluation of potential impacts due to changes in the flow pattern involves evaluating changes in the pattern of groundwater movement with respect to the location of bodies of poor quality water. The flow patterns were evaluated by identifying the direction of groundwater flow between sub-areas. For areas within the Phoenix, Pinal, and Tucson AMAs, existing water quality conditions are identified by reference to the TMP for the associated AMA. The total dissolved solids (TDS) concentration is used as the primary indicator of water quality.

I.C.2. Lowering Levels into Poorer Quality Zones

Evaluation of the potential water quality impacts due to lowering of groundwater levels into bodies of poorer quality water involves comparing the estimated groundwater levels to the depth of poorer quality water. For areas within the Phoenix, Pinal, and Tucson AMAs, existing water quality conditions are identified by reference to the TMP for the associated AMA. When the saturated thickness above the poor quality water zone is reduced, there is the potential for wells to be impacted by the poorer quality water. These results were modified based on judgment, considering such factors as geologic conditions at depths that might influence water quality in wells.

I.C.3. Direct Recharge of CAP Water

Direct recharge of CAP water would influence the water quality of the ambient groundwater through the mixing of these waters. The potential impacts were evaluated by comparing the TDS concentration of CAP water (about 500 to 750 parts per million (ppm)) to the concentration of groundwater in the vicinity of the direct recharge sites.

I.D. Methodology to Evaluate Subsidence Impacts

Subsidence has occurred in many areas of central Arizona since the early 1940s. For example, the USBR's 1976 report, "Geology and Groundwater Resources Report, Maricopa and Pinal Counties," indicated that at least 1,000 square miles in the study area have been affected by subsidence. In addition to lowering of the ground surface, earth fissures can form in response to subsidence.

The mechanism for the subsidence is the compression of saturated clay layers. This compression occurs when groundwater levels decline in adjacent aquifer materials; the lower levels induce flow from the saturated clays, and that flow results in compaction of the clay layers. The subsidence continues until the pore pressure in the clay layers reaches a new equilibrium with the aquifer materials.

The potential for subsidence was evaluated on a qualitative basis. The potential for subsidence was identified if both of the following conditions were present:

- **Geologic Conditions Conducive to Subsidence.** The subsidence potential depends in part on the geologic conditions, specifically the presence of clay materials which are subject to compaction. For areas that have experienced significant groundwater declines, the potential for substance can be identified simply by the identification of historical subsidence. For areas without significant historical groundwater declines, it requires consideration of the presence of clay materials and an evaluation of whether these clays would be susceptible to compaction.

- **Groundwater Levels Dropping Below Historical Low Levels.** Under the assumption that conditions in compressible clays would be in equilibrium with historical low groundwater levels, it is assumed that a drop in groundwater levels below the historical minimum could trigger subsidence. While it is possible that subsidence could begin with levels above the minimum historical level (if conditions in the compressible clay did not reach equilibrium with this groundwater level), it is a reasonable assumption for the purpose of this analysis.

The identification of areas with historical subsidence and geologic conditions conducive to subsidence was accomplished by review of available published reports that addressed the areas of interest. The evaluation of groundwater levels is based on the projected future groundwater levels for the area, as presented earlier in Section A of this appendix. In particular, the maps show changes in groundwater levels in sub-areas for the No Action Alternative from 2001 to 2051, and showing groundwater level impacts in year 2051 by sub-area is helpful in identifying potential subsidence impacts.

This evaluation provides a qualitative assessment of subsidence potential. It does not attempt to quantify the magnitude of subsidence that might ultimately occur, or to locate subsidence impacts other than within the sub-area. Impacts of the Settlement and Non-Settlement Alternatives are evaluated against the No Action Alternative. To the extent that subsidence would occur under the No Action Alternative, a reduction in subsidence potential from the No Action Alternative would be a positive subsidence impact.

II. RELATIONSHIPS BETWEEN ANALYSIS INPUTS AND GROUNDWATER LEVEL IMPACTS

The groundwater level impacts estimated in this analysis are in large part a reflection of the inputs to the analysis presented above. A detailed discussion of the inputs as defined in the background assumptions may be found in Appendix A. This section presents a general description of how these inputs are ultimately reflected in the estimated groundwater levels. The discussion of impacts in particular sub-areas presented in the later sections of this appendix provide a brief indication of the basis of those impacts, in relation to the conceptual background presented here.

II.A. Basis of Groundwater Level Impacts

Groundwater level impacts reflect both the influence of net pumping (i.e., differences between pumping and recharge) within a sub-area, and the influence of groundwater flows between sub-areas.

II.A.1. Net Pumping

All other things being equal for a given sub-area, groundwater levels would be higher with less net pumping, and lower with greater net pumping. The magnitude of that impact would reflect several factors, such as specific yield and the intensity of the net pumping. The specific yield governs how much the groundwater level would change for a given change in groundwater storage.

The intensity of the net pumping is related to how much net pumping there is in relation to the size of the sub-area. For example, an increase in net pumping of 5,000 afa would have a larger impact on groundwater levels for a sub-area with an area of 10,000 acres (0.5 af per acre) than for a sub-area with an area of 50,000 acres (0.1 af per acre).

II.A.2. Groundwater Flows Between Sub-areas

Groundwater underflow between sub-areas is one of the components considered in the hydrologic inventory analysis. Changes in those underflows can, therefore, impact the groundwater levels estimated for sub-areas. Changes in the groundwater underflows reflect changes in groundwater levels in adjacent sub-areas, with greater changes of groundwater levels in the adjacent sub-areas resulting in greater impacts to groundwater levels in the sub-area of interest. The sensitivity of a given sub-area's groundwater level to adjacent groundwater levels would reflect the parameters used to estimate the groundwater flows using Darcy's Law (transmissivity, underflow perimeter width, and distance used to estimate hydraulic gradients).

The largest groundwater level impacts occur in response to changes in net pumping within a sub-area. Groundwater level impacts resulting from changes in underflow from adjacent areas can be difficult to clearly recognize in a sub-area, except when impacts due to changes in net pumping are relatively small and/or there are relatively large groundwater level changes in the adjacent sub-area.

II.B. Typical Patterns of Groundwater Level Impacts

The specific groundwater level impact for any specific alternative and sub-area depends on the individual characteristics of that sub-area and on the specific operations considerations for the entities within that sub-area. However, there are some typical patterns in the estimated inputs to the groundwater analysis that apply to a number of entities in various sub-areas. This section discusses these "typical" patterns, and how they generally show up as groundwater level impacts. These patterns guide the evaluation of the analysis results for specific areas, which are presented later.

While the typical patterns of groundwater level impacts discussed in the sub-sections which follow are useful in evaluating results, it should also be recognized that there are a number of complicating factors which must be considered to evaluate groundwater level impacts in a specific sub-area. One factor is that the impacts in a given sub-area often reflect a mix of these impacts. For example, some sub-areas would include pumping and recharge reflecting both NIA and M&I entities. A second factor is that if the changes in pumping and recharge are not very intense in a sub-area, the groundwater level impacts for the sub-area may be dominated by changes in groundwater flows caused by larger groundwater level impacts in adjacent sub-areas.

II.B.1. NIA Entities

Groundwater level impacts for NIA entities reflect an interplay between a number of factors including the following:

- **Size of Ag Pool and NIA Allocations**. While there are variations in the distribution of the Ag Pool and NIA allocations, the total of the Ag Pool volume and (for Alternative 3B) the NIA allocation over the 50-year period often explains the relative impacts of alternatives.

These volumes are discussed in some detail in Appendix A. The total volume of these pools for the various alternatives are:

Alternative	Total Ag Pool and Allocation (Million af over 50-year period)
No Action	11.2
Settlement	12.6
Non Settlement 1	11.2
Non-Settlement 2	10.2
Non Settlement 3A	11.6
Non Settlement 3B	8.9

- **Ag Pool Allocation**. The amount of the Ag Pool water that each entity receives depends on the assumptions used to allocate that water. For the Settlement Alternative, the Ag Pool is distributed based on the CAWCD's proposed distribution [CAWCD Board Agenda Brief, Item No. 5, for April 6, 2000 Board Meeting, Larry Dozier]. For all other alternatives, the Ag Pool is distributed based on the percentages listed in Table I-19.

Table I-19
CAP Ag Pool Percentage Distribution

	Settlement Alternative	All Non-Settlement Alternatives
CAIDD	27.02%	33.1%
CHCID	0.14%	0.5%
CMID	1.39%	-
HVID	7.98%	5.3%
HHID	8.28%	4.5%
MSIDD	27.02%	32.4%
MWD	0.97%	-
NMIDD	8.58%	10.3%
QCID	2.19%	7.8%
RWCD	2.18%	3.8%
RID	2.31%	-
SCIDD	8.13%	-
STID	0.34%	1.1%
TID	0.42%	1.3%
Total	96.95%	100.0%

While the No Action Alternative should generally be, on average, the best alternative for NIA entities, the different distribution of the Ag Pool used for the Settlement versus Non-Settlement Alternatives may change that assessment for individual NIA entities. For example, MSIDD receives a smaller percentage (27.02 percent) of a larger Ag Pool under the Settlement Alternative than under the No Action Alternative (32.4 percent) with the net effect of MSIDD receiving less Ag Pool water under the Settlement Alternative.

- **In-Lieu Recharge Pool**. NIA entities participate to varying degrees in the in-lieu Recharge Pools. The size of that pool and the distribution of that pool to NIA entities influence the groundwater level impacts. Also, the groundwater level hydrographs would often reflect the reductions in the availability of recharge water over time (for example, for CAIDD, MSIDD, NMIDD, QCID, and HIDD, in-lieu recharge is not available after 2017, which appears as a point of inflection on the groundwater level hydrographs in the sub-areas containing these entities). While the Recharge Pool is separate from CAP recharge supplies for CAGRD (which is not available to NIA entities), the size of the CAGRD supplies influence how much of the Recharge Pool is available to NIA for in-lieu recharge. Thus, the combined volume of the Recharge Pool and the CAGRD supplies provides an indication of the potential impact of in-lieu recharge supplies on groundwater for NIA. This volume is summarized below for each alternative:

Alternative	Combined Recharge Pool and CAGRD Supplies (Million af over 50-year period)
No Action	18.3
Settlement	10.2
Non-Settlement 1	17.0
Non-Settlement 2	16.4
Non-Settlement 3A	14.1
Non-Settlement 3B	13.7

- **Reductions in Cropped Acreage**. In interpreting the estimated groundwater levels, it should be recognized that the cropped acreage (and, therefore, water demands) can vary based on the socioeconomic analysis and to reflect urbanization lands presently developed for irrigated agriculture. These impacts can vary between the different entities. For example, these factors are primary in understanding the projected groundwater elevations in the Queen Creek area.

II.B.2. Indian Entities

The impacts to Indian entities for the various alternatives vary in response to the allocation of CAP water that is generally specific to each Indian entity. CAP water available to Indian entities by entity and alternative is summarized in Table I-20. The impacts also reflect the assumptions of the analysis with respect to the timing of build-out under each alternative. Those build-out assumptions result in differences in the timing of demands and availability of supplies for the alternatives.

Table I-20
Indian Sector CAP Water Use
(in thousand afa)

Alternative	GRIC	TON: San Xavier District	TON: Schuk Toak District	SC Apache Tribe	Navajo And Hopi	GRIC Groundwater Pumping
Settlement	266.6	42.0	16.0	31.7	0.0	157.0
No Action	173.1	27.0	10.8	31.7	0.0	80.0
Non-Settlement 1	208.7	27.0	10.8	31.7	0.0	80.0
Non-Settlement 2	248.2	42.0	16.0	55.1	13.5	80.0
Non-Settlement 3A	343.3	42.0	16.0	71.7	13.5	139.4
Non-Settlement 3B	343.3	42.0	16.0	71.7	13.5	139.4

The changes in the pumping and recharge associated with the Indian entities is often relatively intense, so there are often relatively large impacts in these areas

II.B.3. Municipal and Industrial Entities

Impacts due to changes in pumping and recharge between alternatives for M&I entities generally reflect the volume of CAP water available to M&I entities, recharge supplies for M&I areas, and use of effluent. These factors are discussed below:

- **Volume of CAP Water Available to M&I Entities**. The volume of water available to M&I entities includes contracted M&I water, NIA-priority allocations to M&I entities, and M&I leases. The differences in supply from the No Action Alternative are relatively small, and these supplies are generally widely distributed, so that impacts associated with these supplies are relatively diffuse and difficult to identify in an individual sub-area. For perspective, currently 538,031 afa of CAP water are contracted to M&I users, and Salt River Valley users have access to considerable Salt and Verde River supplies. The total of the additional supplies for the various alternatives are summarized below:

Alternative	Additional CAP Allocation to M&I Users (afa)	Additional Indian Leases to M&I Users (afa)
No Action	0	0
Settlement	65,647	41,000
Non-Settlement 1	65,647	0
Non-Settlement 2	0	0
Non-Settlement 3A	0	0
Non-Settlement 3B	71,815*	0

*71,815 afa is NIA-priority. For purposes of analysis, 65,647 afa are considered for direct use with the remainder being recharged to firm up its priority.

- **Recharge Supplies**. The availability of recharge water to M&I entities can strongly influence the groundwater level impacts. Where direct recharge facilities are present and used for long-term storage, the impacts related to the recharge activities tend to completely dominate the impacts associated with the CAP water available for M&I use. For recharge operated on a "put and take" basis (i.e., water is recovered within one year of recharge), the analysis has treated such CAP deliveries as direct deliveries (i.e., there is no impact to groundwater at the level of geographic and temporal refinement of the analysis).

- **Use of Effluent**. Effluent can be used as a supplemental supply by entities which do not receive additional CAP water under an alternative. Currently, substantial amounts of effluent generated in the Salt River Valley are treated at the 91st Avenue wastewater treatment plant and discharged to the Gila River. This analysis assumes that this practice would continue to occur for the current levels of effluent generation. Additional effluent would be generated with increasing population. Some of this effluent would serve industrial demands; some would be treated and discharged on-site. This analysis assumes that effluent used to satisfy M&I demands would not be of a quantity to impact current levels of discharge to the Gila River. It is also assumed that on-site recharge of effluent would not significantly impact groundwater levels or quality.

II.C. Shortage Conditions

The hydrologic sequence used to evaluate groundwater conditions includes "normal" years of CAP availability from 2001 to 2043, and "shortage" years from 2044 to 2051. This sequence is generally representative of the most recent USBR water supply analyses, which show an average of eight years of shortage over the 50-year period and, further, that the shortages generally occur at the end of the 50-year period. More detail is available in the discussion of shortage in the "Discussion of Key Assumptions" section of Appendix A.

The impact of the assumed shortage condition tends to vary reflecting the sector, as described briefly below.

- **NIA Entities.** The availability of CAP water to NIA entities is already limited before 2044 due to the "pinch out" of the Ag Pool, so that the shortage conditions do not tend to result in a dramatic change in CAP availability or in groundwater level trends. However, for entities which are continuing to receive NIA-priority CAP water for in-lieu recharge in the later years, the reduction in CAP water available under shortage does produce increased declines in groundwater levels.

- **Indian Entities.** In general, Indian entities receive high priority CAP water that is generally not impacted by shortage, so that the shortage conditions do not tend to result in dramatic changes in CAP water availability or in groundwater level trends. The exception is that a portion of the CAP water available to GRIC for some alternatives has a NIA priority and a portion of the GRIC's Indian-priority CAP water is affected by the shortage conditions.

- **M&I Entities.** The shortage conditions do produce relatively large impacts in M&I areas in the vicinity of direct recharge facilities. Those impacts reflect the reductions in the Recharge Pool.

The magnitude of the groundwater level changes during the shortage period near direct recharge facilities also tend to vary between alternatives, with greater drops in groundwater levels occurring under the Settlement Alternative and Non-Settlement Alternatives 1 and 3B. The greater drops in groundwater levels in some sub-areas for these alternatives relative to the No Action Alternative and Non-Settlement Alternatives 1 and 3A result from additional pumping for recovery of AWBA groundwater credits in those areas.

III. EVALUATION OF ALTERNATIVES

Groundwater conditions were evaluated for the No Action, Settlement, and Non-Settlement Alternatives using the methodology previously described. These evaluations cover the period from 2001 to 2051. The process used for the evaluations is presented first. This is followed by discussion of groundwater conditions broken out by geographical area.

Water level, water quality, and subsidence impacts are defined as the incremental difference between the conditions under the Settlement and Non-Settlement Alternatives relative to the conditions under the No Action Alternative. Because the No Action Alternative is the basis of comparison, the discussion of conditions under the No Action Alternative tends to focus on "absolute" changes in groundwater conditions. In contrast, discussion of the Settlement and Non-Settlement Alternatives focus on changes relative to the No Action Alternative. Because of this different focus, conditions for the No Action Alternative are presented in separate sections for each geographic area, while the discussion of the Settlement and Non-Settlement Alternatives has been combined.

The distinction between the focus of these alternatives results in different results being discussed. For example, groundwater level condition discussions under the No Action Alternative tend to focus on the change in groundwater levels from year 2001 to year 2051, while discussions for the Settlement and Non-Settlement Alternatives tend to focus on the difference in year 2051 groundwater levels relative to the No Action Alternative. It is noted that the analysis performed is expected to provide a better estimate of the impact (i.e., change from the No Action Alternative) than of the absolute groundwater levels.

III.A. Analysis Process

The analysis process included four general steps:

- Review of published studies and reports and development of a conceptual-level understanding of the hydrologic inventory, and water quality and subsidence conditions.

- Development of a hydrologic inventory analysis for historical conditions and comparison of the resulting estimated historical groundwater levels to observed historical levels, as a means to evaluate the capabilities of the hydrologic inventory analysis.

- Use of the hydrologic inventory to evaluate projected future groundwater elevations for alternatives and to estimate the impacts for each alternative (where the impacts represent the changes in groundwater elevations from the No Action Alternative for the alternative under consideration).

- Evaluation of potential changes in groundwater quality and subsidence due to changes in groundwater levels.

These four steps are discussed in the sub-sections which follow.

III.A.1. Develop Conceptual Understanding of Hydrologic System

The first step in the analysis process was to develop a general understanding of the geology, hydrology, water quality, and subsidence potential in the area being considered by review of published studies and reports. This review provided a conceptual understanding of the hydrologic inventory needed to implement the hydrologic inventory analyses used for this study. Basic data used in the analyses were also identified during this initial review process.

III.A.2. Develop Hydrologic Inventory Analyses and Evaluate Historical Conditions

Information from published sources was used to estimate aquifer parameters (specific yield and aquifer transmissivities) and historical components of the hydrologic inventories. For some years, the estimated components could be taken directly from existing model studies, which also depend on identifying the components of the hydrologic inventory. In other years, the components needed to be estimated based on other reported values. Typically, substantial judgment was needed to evaluate these historical components of the hydrologic inventories and reconcile information from the various available sources. In some cases, data were limited and the estimated quantities were largely based on judgment.

The hydrologic inventories were generally developed using a relatively long period of historical record. This is consistent with the ultimate use of the hydrologic inventory analyses is to evaluate impacts over a relatively long projection period (from year 2001 to 2051). The emphasis on evaluating trends over a relatively long period is also consistent with the level of detail that could be developed for the hydrologic inventories. Some of the simplifying assumptions required for the analyses (such as the evaluation for some components of the hydrologic inventory on a long-term average basis rather than year-by-year) limit the capability to identify short-term trends.

The results of the hydrologic inventory analyses using historical data were compared to observed groundwater level trends. Because the groundwater levels estimated using the hydrologic inventories represent average levels within sub-areas, the most appropriate basis of comparison is with historical average groundwater levels for the same areas estimated using groundwater elevation contour maps. An average groundwater elevation for an area was obtained by measuring areas defined by groundwater elevation contours and developing a weighted average. In some cases, comparisons were made with hydrographs for individual wells. Changes in the groundwater flow pattern implied from the hydrologic inventory results were also compared to historical flow patterns.

III.A.3. Evaluate Impacts of CAP Allocation on Groundwater Levels

The hydrologic inventories were used to evaluate the impacts of CAP allocations on groundwater levels over the 2001 to 2051 period. The projected components of the hydrologic inventory were estimated based on projected water demands and surface water supplies (with demands in excess of surface water supplies being met by pumping groundwater within legally prescribed limits).

The impacts are computed as the difference between the alternative being considered and the No Action Alternative. The hydrologic inventory analyses are expected to provide a better estimate of the relative impacts (i.e., a comparison of two analyses to identify the incremental impacts of the changed hydrology on groundwater levels) than of the absolute groundwater levels. This is because non-CAP components of the hydrologic inventory would be the same for both the No Action Alternative and the alternative under consideration. Because the influence of non-CAP components is present in both the No Action Alternative and the alternative under consideration, errors associated with a component of the inventory present in both alternatives would tend to cancel out in the comparison.

Because the No Action Alternative is the basis of comparison to determine impacts for the other alternatives, the discussion of the No Action Alternative must focus to some extent on absolute groundwater levels, rather than impacts. Further, recognizing the limitations in the hydrologic inventory analysis and in estimating inputs to the hydrologic inventory analysis over the 50-year analysis period, emphasis was given to evaluating and discussing the larger groundwater level impacts. While a 25-foot impact over a 50-year period is relatively small, discussion was in general focussed on impacts of at least that magnitude.

III.A.4. Identify Potential Water Quality and Subsidence Impacts

The estimated groundwater level impacts were used to help evaluate the potential for water quality and subsidence impacts. As with the water level impacts, water quality and subsidence impacts were not considered to be very significant where the water level impacts were less than 25 feet.

III.B. Groundwater Level Analysis for the Tucson Area

A hydrologic inventory analysis was performed for groundwater in the alluvium and basin fill materials in the Tucson area. The study area considered for the Tucson area and the sub-areas used in the analysis are shown on Figure I-4. It essentially is bounded by the Santa Catalina and Santa Rita Mountains to the east and the Tucson, Sierrita, and Tumacacori Mountains to the west. The analysis area runs from Tubac in the south to the Cortaro-Marana Irrigation District (CMID) and the Oro Valley area in the north.

Drainage in the study area is primarily provided by the Santa Cruz River, which enters the study area at the southern end and flows northerly to the Cortaro-Marana area and, thence, out of the study area to the Avra Valley. Drainage is also provided by various creeks and washes which are tributary to the Santa Cruz River, such as the Canada Del Oro, Sonoita Creek, Rillito Creek, Sabino Creek, Agua Caliente Wash, Tanque Verde Creek, and Pantano Wash. Before 1870, flow was intermittent for most of the river. Development has resulted in more regular flow in parts of the Santa Cruz River (particularly downstream of Tucson), supported by return flows and effluent discharges to the river.

Development in this area includes urban (particularly Tucson and nearby areas) and agricultural development. Much of the development has occurred along the Santa Cruz River. Also, there are significant mining operations, particularly along the Sierrita Mountains.

III.B.1. Existing Groundwater Conditions

The existing groundwater conditions were described in the USGS WRI-93-4196, "Simulation of Ground-Water Flow and Potential Land Subsidence, Upper Santa Cruz Basin, Arizona." The following discussion is primarily based on information presented in that report.

III.B.1.a. Geology

The groundwater resources of interest are contained in the alluvial deposits that fill the basin between the adjacent mountains. These deposits consist of gravel, sand, silt and clay. In general, the sediments are coarser along the edges of the basin and finer grained toward the central axis of the upper Santa Cruz Basin. There are also evaporitic deposits in the central portions of the basin.

The USGS split the basin fill materials into an upper and lower unit. In the context of the geology described elsewhere (see the section on the Pinal/Salt River Valley), the upper unit for the Tucson area appears to be analogous to the "upper alluvial unit," while the lower unit for the Tucson area appears to be analogous to a combination of the "Lower Conglomerate Unit" and the "Middle Fine-Grained Unit."

The upper alluvium in the Tucson area consists of gravel, sand and clayey silt. It ranges in thickness from 100 to more than 1,000 feet. The USGS study indicates these deposits tend to be more coarse-grained in the northerly part of the basin (apparently corresponding to the MDWID, Oro Valley, and CMID East sub-areas). The USGS study indicates that the upper alluvium may have greater potential for subsidence due to lowering groundwater levels than the lower alluvium.

The lower alluvium in the Tucson area consists of gravel, conglomerate, evaporites, clayey silt, and mudstone. The lower alluvium can be thousands of feet thick in the central portions of the basin.

III.B.1.b. Groundwater Occurrence and Movement

Groundwater generally occurs under unconfined to partially confined conditions to a depth of about 1,500 feet.

The pattern of flow in the Tucson area is generally from south to north, paralleling the Santa Cruz River. There is also generally a component of flow from the margins of the basin toward the Santa Cruz River. This pattern has been maintained over a long time period for the Tucson area.

III.B.1.c. Groundwater Quality

Existing groundwater quality conditions were identified with respect to both general mineral constituents and for specific contaminants of interest.

III.B.1.c.(1) General Minerals

The 1974 USGS Map I-844-I ("Dissolved-Solids Content of Ground Water in the Tucson Area, Arizona") was used to define these conditions. Information on TDS was also reviewed from the TMP for the Tucson AMA (Figure 7-3 of that document). That information is consistent with the USGS map. In general, groundwater along the margins of the valley has less than 500 ppm TDS. Most of the water in the central portion of the valley, associated with the Santa Cruz River and generally beneath Interstate 10, has concentration of TDS between 500 and 1,000 ppm. There are also some pockets of water with TDS in the range of 1,000 to 3,000 ppm, in areas located in portions of the San Xavier East, Tucson East, Tucson West, and CMID East sub-areas. The text which accompanies USGS Map I-844-L indicates that, in general, TDS concentrations tend to decrease with increasing depth.

The general distribution of other constituents was identified from the 1974 USGS Map I-844-L ("Map Showing Chemical Quality of Ground Water for Public Supply in the Tucson Area, Arizona") which shows the quality for the upper 300 feet of the saturated alluvium with respect to fluoride, nitrate, and hardness. This was supplemented with consideration of more recent water quality data presented in the TMP for the Tucson AMA. In general, hard water (exceeding 150 ppm) occurs beneath the Santa Cruz River, beneath Interstate 10, and in the sediments between the Santa Cruz River and the Santa Rita Mountains.

Pockets of water with high nitrate (over 45 ppm) and fluoride (over 1.4 ppm) also occur beneath the Santa Cruz River. These pockets are located from approximately Green Valley in the south to the Cortaro-Marana area to the north. Also, the TMP for the Tucson AMA shows some water with fluoride exceeding four ppm in the vicinity of Interstate 10 east of the Santa Cruz River.

III.B.1.c.(2) Other Constituents

Other water quality constituents were considered with reference to information presented in the Tucson AMA TMP. Information in that document included discussion for metals, volatile organic compounds, petroleum hydrocarbons, and pesticides. Maps are also included showing the locations and results of test analyses for metals and volatile organic compounds. The TMP also identifies several "specific contamination areas." For the Tucson area, the sites shown in the Management Plan are located in the Tucson East, Tucson West, CMID East, and San Xavier East sub-areas.

III.B.1.d. Subsidence

Subsidence has occurred historically in the Tucson area. The TMP for the Tucson area indicated that about one-half foot of land subsidence had occurred south of Davis-Monthan Air Force Base by 1980, and that between 1980 and 1995, from 0.02 to 0.18 feet of compaction subsidence had occurred at sites monitored by Tucson Water.

The USGS prepared estimates of potential future subsidence in the Tucson area as part of its groundwater modeling studies. Maximum potential subsidence was estimated as follows in that study:

- **Tucson Central Well Field.** The maximum potential subsidence was estimated to range from about 1.2 to 12 feet, depending on the assumptions used with regard to aquifer compressibility. These estimates are based on water levels declining more than 400 feet below 1940 levels. This subsidence would occur on lands within the Tucson East and Tucson West sub-areas.

- **Tucson Santa Cruz Well Field.** The maximum potential subsidence was estimated to be as much as four feet in this area and could impact lands in the San Xavier East, Vail, Green Valley Central, and Green Valley East sub-areas.

The USGS modeling study indicated that the upper aquifer unit may be more susceptible to subsidence than the lower aquifer unit.

III.B.2. Details of Analysis Methodology

The sub-areas were defined so that the hydrologic inventory could reflect the historical pattern of flow in the Tucson area. The locations of the sub-areas were shown earlier on Figure I-4. In general, sub-areas were defined along the Santa Cruz River, with other sub-areas to the immediate east or west. This allows the analysis of the Tucson area to reflect both the overall north-south groundwater flow beneath the Santa Cruz River and the flow toward the river from the adjacent mountains. Also, it is noted that much of the historical water use and groundwater pumping were developed near the Santa Cruz River. Divisions between sub-areas from north to south were generally made to allow impacts to be identified for specific entities of interest for this study.

The analysis for the Tucson area is "linked" to the analysis for the Avra Valley. This link is between the CMID East sub-area of the Tucson area and the CMID Central sub-area of the Avra Valley.

Several assumptions specific to the Tucson area were made while performing the analysis. These assumptions include the following:

- Use of CAP water for M&I purposes in the Tucson area would be phased in during the first five years of the analysis.

- CAP M&I allocations will be used to perform "put and take" recharge at direct recharge facilities as a first priority, and additional direct use is assumed as needed to utilize the allocations. Recharge would be performed at presently proposed sites in both the Tucson area and Avra Valley, and recovery would be performed at existing well fields and at City of Tucson wells in the south Avra Valley.

III.B.3. Evaluation of Historical Conditions and "Calibration"

The hydrologic inventory analysis was used to evaluate groundwater conditions from about 1941 to 1999. Aquifer parameters for the sub-areas were developed from model parameters presented in USGS WRI 93-4196. Specific yields were estimated based on review of Figure 15 of that report, while transmissivities were estimated based on review of Figure 12 of that report, which presents an overall transmissivity under pre-development conditions (i.e., before impacts of dewatering).

Estimates were prepared for the components of the historical hydrologic inventory. These components include:

- Recharge
  - Mountain front recharge
  - Groundwater inflows from margins of the analysis area
  - Streamflow infiltration
  - Incidental recharge

- Discharge
  - Phreatophyte evapotranspiration
  - Groundwater outflows from margins of the analysis area
  - Groundwater pumping

Table 4 of the USGS modeling study was used to estimate these components for the 1941 to 1986 period covered by the USGS study. For later years, the components were estimated through review of other published sources, including records of the AMA and data presented in the management plans for the Tucson AMA.

Groundwater level hydrographs were prepared to compare groundwater levels estimated using the hydrologic inventory to observed groundwater levels and groundwater levels estimated using the USGS numerical groundwater model. The hydrologic inventory is able to reflect the large scale trends in groundwater levels which have historically occurred.

Evaluation of the estimated historical groundwater levels also included a comparison of the flow pattern indicated by the results of the hydrologic inventory analysis to the observed flow pattern. The hydrologic inventory analysis showed essentially the same pattern of flow, with flow from the margins of the basin towards the Santa Cruz River, and flow beneath the Santa Cruz River from south to north.

III.B.4. Analysis of Alternatives

The hydrologic inventory analysis was used to estimate the groundwater impacts for each alternative, where the impacts are defined as the difference between the groundwater levels projected for a given alternative and the groundwater levels projected for the No Action Alternative. The analysis for each alternative reflects estimated future demands, an assessment of the water supplies used to meet those demands, and consideration of recharge (both artificial and incidental).

The No Action Alternative serves as the basis of comparison to determine impacts for the other alternatives, and, therefore, focuses to some extent on absolute groundwater levels, while discussion of the Settlement and Non-Settlement Alternatives focuses on impacts (differences from the No Action Alternative).

III.B.4.a. No Action Alternative

Changes in groundwater levels, groundwater quality, and subsidence are discussed in the sub-sections which follow.

III.B.4.a.(1). Groundwater Levels

Projected hydrographs of average annual groundwater levels for the No Action Alternative for each sub-area in the Tucson area are shown on Figures I-5 through I-18. Projected levels for the other alternatives are also shown on those same figures and will be discussed later in the section that addresses the Settlement and Non-Settlement Alternatives. In addition to these hydrographs, Figure I-19 shows the change in the average groundwater elevation for each sub-area from 2001 to 2051 under the No Action Alternative.

As shown on Figure I-19, changes in groundwater levels under the No Action Alternative during the 2001 to 2051 period range from a decline of 111 feet to a rise of 57 feet. Most of the sub-areas experience declines in groundwater levels over the 2001 to 2051 period, reflecting continued reliance on groundwater to meet demands and increases in demands associated with increased population. In contrast, groundwater levels rise in the Tucson West and San Xavier East sub-areas by nine to 57 feet respectively.

The groundwater levels reflect the transition to full use of CAP supplies during the period 2001 to 2005. The use of CAP water includes both direct use and recharge. For sub-areas with direct use or with recharge facilities, the buildup in CAP use can be seen by the groundwater level trends shown on the hydrographs. For example, the hydrograph for the MDWID sub-area, presented on Figure I-7, shows the rate of groundwater level decline slowing during the first five years. For other locations, recovery occurs at some distance from the associated recharge, and the transition to full use of CAP water is not seen on the hydrographs in such recovery areas. An example is the Green Valley Central sub-area, where the transition to full CAP use cannot be seen clearly on the hydrograph shown on Figure I-14.

Direct recharge of CAP M&I allocations occurs at facilities in both the Tucson area and the Avra Valley area. In the Tucson area, M&I allocations are recharged in the Pima Mine Road facilities (located in the San Xavier East sub-area), the Santa Cruz Managed Recharge Project facilities (located in the Tucson West and CMID East sub-areas), and the Avra Valley Recharge Project facilities (located in the CMID East sub-area, and the CMID Central sub-area of the Avra Valley analysis). Also, a portion of the CAP water available to the San Xavier District would be directly recharged in the San Xavier East sub-area. The rise in groundwater levels from 2001 to 2051 in the San Xavier East and Tucson West sub-areas are, in part, a reflection of the direct recharge in those sub-areas.

The amount of CAP water recharged depends in part on the available recharge capacity. It is assumed that the full recharge capacity is available in year 2017. The increased rate of groundwater level rise in the San Xavier East sub-area in year 2017, shown on Figure I-11, is a reflection of greater recharge due to greater available recharge capacity.

Under the No Action Alternative, a groundwater mound would develop beneath the San Xavier East sub-area in response to direct recharge of both M&I and Indian CAP allocations. The mound would result in a flow reversal between the San Xavier East and Vail sub-areas by year 2051 (i.e., there would be flow from the San Xavier East sub-area to the Vail sub-area).

III.B.4.a.(2). Groundwater Quality

The regional pattern of flow for the No Action Alternative would generally be similar to existing conditions, with flow from the margins of the basin toward the Santa Cruz River, and beneath the Santa Cruz River from south to north. The exception is the flow reversal which would occur between the San Xavier East and Vail sub-areas. That flow reversal could result in the movement of poorer quality water beneath the Santa Cruz River toward the Vail area to the east. However, the CAP water being used for recharge would have a lower TDS concentration than the poorer quality water in the San Xavier East sub-area and would tend to provide for an offsetting improvement in groundwater quality. Therefore, substantial changes in groundwater quality would not be anticipated under the No Action Alternative for these flow conditions.

Groundwater depressions did not develop for any of the Tucson sub-areas for the No Action Alternative. This flow pattern would tend to help maintain the existing regional salt balance.

Bodies of poor quality water at depth were not identified in the Tucson area. Therefore, there would not be anticipated potential water quality impacts due to lowering of groundwater levels into such bodies of groundwater.

III.B.4.a.(3). Subsidence

There is the potential for subsidence in the Tucson area, as groundwater levels decline in most sub-areas by year 2051. Based on consideration of the geological conditions and documented subsidence in the Tucson area, it is reasonable to anticipate potential subsidence in areas that experience a drop in groundwater levels from present conditions. Increases in groundwater levels in the Tucson West and San Xavier East sub-areas would tend to prevent subsidence in these sub-areas.

I.B.4.b. Impacts of the Settlement and Non-Settlement Alternatives

Changes in groundwater levels, groundwater quality, and subsidence relative to the No Action Alternative are discussed in the sub-sections which follow.

III.B.4.b.(1) Groundwater Levels

Projected average annual groundwater level hydrographs under the Settlement and Non-Settlement Alternatives for each sub-area were shown previously on Figures I-5 through I-18, which show how groundwater levels within a sub-area vary over the 50-year period. Projected levels for the No Action Alternatives are also shown on those same figures. The geographic distribution of the groundwater level impacts between sub-areas in year 2051 (i.e., difference in groundwater levels from the No Action Alternative) is shown for the various alternatives on Figure I-20 (Settlement Alternative), Figure I-21 (Alternative 1), Figure I-22 (Alternative 2), Figure I-23 (Alternative 3A), and Figure I-24 (Alternative 3B).

The Settlement Alternative and all of the Non-Settlement Alternatives would have the same reversal in flow in year 2051 between the San Xavier East and Vail sub-areas as occurs under the No Action Alternative. Also, all of these alternatives would have a reversal in flow between the San Xavier East and Green Valley Central sub-areas, so that a groundwater level depression would develop beneath the Green Valley Central sub-area.

While all of the sub-areas show some impacts under the alternatives, those impacts are often less than 25 feet. Such impacts are not considered to be very significant, given the nature of the analysis performed, the 50-year analysis period, and the assumptions made with regard to water supply and demands. Therefore, the discussion in the following sub-sections focuses on the sub-areas that experience impacts of more than 25 feet under at least one of the alternatives.

III.B.4.b.(1).(i) San Xavier Sub-area

The largest groundwater level impacts occur in the San Xavier East sub-area. The San Xavier District of the Tohono O'odham Nation receives CAP water under all alternatives except Alternative 1. The CAP water is used to meet irrigation demands and for direct recharge. As shown on Figure I-25, there is a positive impact of 73 to 83 feet due to the CAP allocations under those alternatives.

The relatively small differences in impacts for the Settlement Alternative and Non-Settlement Alternatives 2, 3A, and 3B reflect in part differences in groundwater underflows from adjacent areas. As shown on Figure I-25, slightly larger positive impacts occur under the Settlement Alternative and Non-Settlement Alternative 3B, when there are relatively large impacts in the Tucson West sub-area to the north.

Another small difference between the alternatives is the assumed schedule of build-out for irrigated lands in the San Xavier District. The impact of those differences on groundwater levels can be seen on the hydrograph for the San Xavier East sub-area (Figure I-11) as divergences in groundwater levels between alternatives.

III.B.4.b.(1).(ii) CMID East, MDWID, Tucson East, and Tucson West Sub-areas

The patterns of groundwater level impacts in these sub-areas are similar to each other. These patterns reflect the expected "typical" pattern for municipal entities, which dominate these sub-areas. Specifically, entities in these sub-areas receive allocations of additional CAP water under the Settlement Alternative and Non-Settlement Alternatives 1 and 3B, and as shown on Figure I-26, groundwater levels range from 26 to 42 feet higher than the No Action Alternative. In comparison, under Non-Settlement Alternatives 2 and 3A (in which M&I entities do not receive additional allocations of CAP water), the impacts range from a drop of one foot to a rise of 11 feet relative to the No Action Alternative.

The relatively small differences in impacts for the Settlement Alternative and Non-Settlement Alternatives 1 and 3B reflect in part differences in groundwater underflows from adjacent areas. As shown on Figure I-26, groundwater level impacts under the Settlement Alternative and Non-Settlement Alternative 3B are slightly larger than under Non-Settlement Alternative 1, which appears to relate to the larger positive groundwater level impacts in the San Xavier East sub-area.

III.B.4.b.(1).(iii) Green Valley Central Sub-area

Impacts in the Green Valley Central sub-area appear to primarily reflect the influence of changes in groundwater underflow between the Green Valley Central and San Xavier East sub-areas. While the Community Water Company of Green Valley (CWCGV) does receive an allocation of CAP water under some alternatives, that water is used for direct recharge in other locations. Therefore, groundwater pumping is the same for all alternatives, and groundwater levels in CWCGV do not reflect differences in the CAP allocations. As shown on Figure I-25, the magnitude of the groundwater level impacts for each alternative reflects the magnitude of the impact in the San Xavier East sub-area.

III.B.4.b.(2). Water Quality

Groundwater levels in year 2051 throughout the Tucson area are generally higher for the Settlement and Non-Settlement Alternatives than under the No Action Alternative. The only exceptions are one-foot negative impacts (groundwater levels lower than the No Action Alternative) under Non-Settlement Alternatives 2 and 3A in the CMID East sub-area. The generally higher groundwater levels relative to the No Action Alternative and the lack of identified bodies of poor quality water at depth would prevent adverse quality impacts due to lowering levels into deeper bodies of poor quality water.

All of the action alternatives would have a similar flow reversal between the San Xavier East and Vail sub-areas as occurs under the No Action Alternative. Similar to the No Action Alternative, the potential for movement of higher TDS water from beneath the Santa Cruz River to the east could be offset by improvements in TDS concentrations resulting from recharge of CAP water. The development of a groundwater level depression in the Green Valley Central sub-area could result in an adverse salt balance for that sub-area.

There is some potential for improvement of groundwater quality in the vicinity of the direct recharge facilities. The TDS concentration of the CAP water (500 to 750 ppm) is less than the TDS concentration of some groundwater along the Santa Cruz River. Therefore, direct recharge in the San Xavier East, Tucson West, and CMID sub-areas could result in some improvements in groundwater quality in those locations.

III.B.4.b.(3). Subsidence

The Settlement Alternative and all Non-Settlement Alternatives result in positive estimated groundwater level impacts (groundwater levels higher than under the No Action Alternative) for almost all sub-areas. The only exceptions are some very small (one-foot) negative impacts in the CMID East sub-area for Non-Settlement Alternatives 2 and 3A. This indicates that most alternatives would have a positive impact with respect to subsidence in all sub-areas.

In most sub-areas, the positive impact reflects that there is a reduced potential for subsidence. In the Tucson West and San Xavier East sub-areas, the estimated groundwater levels would rise above current levels for the Settlement Alternative and all Non-Settlement Alternatives, so that subsidence would not be anticipated in these areas.

III.C. Groundwater Level Analysis for the Avra Valley Area

A hydrologic inventory analysis was performed for groundwater in the alluvium and basin fill materials in the Avra Valley area. The study area considered for the Avra Valley and the sub-areas used in the analysis are shown on Figure I-27. It is located between the Tucson and Tortolita Mountains to the east and the Silverbell and Roskruge Mountains to the west.

Drainage in the study area is provided by the Santa Cruz River (which enters in the Cortaro-Marana sub-area and exits from the Red Rock sub-area) and its tributaries Brawley, Blanco, and Los Robles Washes. Flow in the Santa Cruz River is strongly influenced by effluent releases to the river in this area.

Development in Avra Valley has primarily been for irrigated agriculture with some limited urbanization and associated M&I use, probably primarily in the Cortaro area along the Santa Cruz River. Much of the land in Avra Valley is also within the Tucson service area, and some urbanization is anticipated in the future.

The AVRA Water Cooperative (Avra Coop) (located in the Avra Coop sub-area) and the Schuk Toak District of the Tohono O'odham Nation (with lands included primarily in the South Avra Valley sub-areas) could receive proposed allocations of CAP water under the alternatives. Lands in Avra Valley in the Tucson service area may receive CAP water as they urbanize. Also, lands in CMID, Kai Farms, and BKW farms would receive CAP water for in-lieu recharge. CAP water would also be used for direct recharge in the Avra Valley Recharge Project located in the West CMID and Central CMID sub-areas, and the Central Avra Valley Storage and Recovery Project (CAVSARP) located in the Avra Coop sub-area. CAP water will also be used for direct recharge in several facilities in the Avra Valley.

III.C.1. Existing Groundwater Conditions

The existing groundwater conditions were described in the USGW WRI 90-4178, "Simulation of Ground-Water Flow and Potential Land Subsidence, Avra Valley, Arizona." The following discussion is primarily based on information presented in that report.

III.C.1.a. Geology

The groundwater resources of interest are contained in the alluvium and basin fill between the adjacent mountains. These deposits consist of gravel, sand, silt and clay. In general, the sediments are coarser along the edges of the Avra Valley and finer grained toward the central axis of the valley. There are also evaporitic deposits in the central portions of the valley.

The USGS (WRI 90-4178) split the basin fill materials into an upper and lower unit. In the context of the geology described elsewhere (see the section on the Pinal/Salt River Valley), the upper unit for Avra Valley appears to be analogous to the "upper alluvial unit," while the lower unit for Avra Valley appears to be analogous to a combination of the "Lower Conglomerate Unit" and the "Middle Fine-Grained Unit."

The upper alluvium in Avra Valley consists of gravel, sand and clayey silt and ranges in thickness from 100 to 1,000 feet. The USGS study indicates that the upper alluvium may have greater potential for subsidence due to lower groundwater levels than the lower alluvium.

The lower alluvium in Avra Valley consists of gravel and conglomerate at basin margins and in the southern part of the basin. Evaporites, clayey silt, and mudstone occur in the north-central part of the basin. The lower alluvium can be thousands of feet thick in the central portions of the valley.

III.C.1.b. Groundwater Occurrence and Movement

Groundwater in the upper 1,000 feet of the underlying sediments generally occurs under unconfined conditions. Under pre-development conditions, groundwater flow was generally from south to north through the Avra Valley. There was groundwater inflow at the south end of Avra Valley from the Altar Valley and from the Tucson area between the Tucson Mountains and the Tortolita Mountains. In the northern part of the Valley, there was also some flow southwesterly toward the Santa Cruz River. Groundwater flow then generally paralleled the Santa Cruz River, exiting the Avra Valley as underflow to the Eloy area between Picacho Peak and Silverbell Mountains. The 1995 water level elevations (presented on Figure 2-7 of the TMP for the Tucson AMA) show a similar pattern of flow under current conditions.

III.C.1.c. Groundwater Quality

Existing groundwater quality conditions were identified with respect to both general mineral constituents and for specific contaminants of interest.

III.C.1.c.(1). General Minerals

The TDS are considered as the general indicator of groundwater quality. The 1974 USGS Map I-844-I ("Dissolved-Solids Content of Ground Water in the Tucson Area, Arizona") was used to define these conditions. Information on TDS from the TMP for the Tucson AMA (Figure 7-3 of that document) was also reviewed, and that information is consistent with the USGS map. In general, groundwater in the Avra Valley area has less than 500 ppm TDS. There are some areas beneath the Santa Cruz River (corresponding to the CMID Central, Red Rock, and the southeastern portion of the CMID West sub-areas) which have a higher TDS concentration in the range of 500 to 1,000 ppm, as do some areas in the Picacho and Tortolita sub-areas.

The general distribution of other constituents was identified from the 1974 USGS Map I-844-L ("Map Showing Chemical Quality of Ground Water for Public Supply in the Tucson Area, Arizona") which shows the quality for the upper 300 feet of the saturated alluvium with respect to fluoride, nitrate, and hardness. This was supplemented with consideration of more recent water quality data presented in the TMP for the Tucson AMA. In general, hard water (exceeding 150 ppm) occurs in the Avra Valley west of Brawley Wash, along the southern end of the Avra Valley lying north of the Sierrita Mountains, and beneath the Santa Cruz River.

A body of high nitrate water (over 45 ppm) occurs beneath much of the Santa Cruz River in the Avra Valley. There is also a pocket of water with high fluoride concentrations (over 1.4 ppm) in the sediments northwesterly of the Tucson Mountains.

III.C.1.c.(2). Other Constituents

Other water quality constituents were considered with reference to information presented in the Tucson AMA TMP. The Tucson TMP includes discussion for metals, volatile organic compounds, petroleum hydrocarbons, and pesticides. Maps are also included in the TMP showing the locations and results of test analyses for metals and volatile organic compounds. These maps indicate very limited data available for the Avra Valley.

The TMP also identifies several "specific contamination areas." One of the sites is located in the Avra Valley (the "ESCO" site).

III.C.1.d. Subsidence

Subsidence has occurred historically in the Avra Valley. The Tucson AMA TMP indicated that subsidence of at least 1.1 feet has occurred in the northern Avra Valley and that an earth fissure developed in 1988 which damaged the CAP Aqueduct.

The USGS prepared estimates of potential future subsidence in the Avra Valley as part of its groundwater modeling studies. The maximum potential subsidence was estimated to range from about 0.9 to 14.7 feet, depending on the assumptions used with regard to aquifer compressibility. Lands with projected subsidence based on the USGS study were located in the Cortaro-Marana Central sub-area, Cortaro-Marana West sub-area, Red Rock sub-area, and the Avra Valley North sub-area.

Based on consideration of the geologic conditions throughout the Avra Valley and the documentation of historical subsidence, it is reasonable to anticipate that subsidence could occur in any of the Avra Valley sub-areas if the groundwater levels decline in that sub-area.

III.C.2. Details of Analysis Methodology

Eight sub-areas were defined for the Avra Valley area, located as shown on Figure I-27. The sub-areas were selected to reflect the general south to north flow in Avra Valley, and flow parallel to the Santa Cruz River. The analysis for Avra Valley is "linked" to the analysis for the Tucson area. This link is between the CMID East sub-area of the Tucson area and the CMID Central sub-area of the Avra Valley.

Several assumptions specific to the Avra Valley were made to perform the analysis. These assumptions include:

- ♦ Use of CAP water for M&I uses in the Avra Valley would be phased in during the first five years of the analysis.

- ♦ CAP M&I allocations will be used to perform "put and take" recharge at direct recharge facilities as a first priority, and additional direct use is assumed as needed to utilize the allocations. Recharge would be performed at presently proposed sites in both the Tucson area and Avra Valley, and recovery would be performed at existing well fields and at City of Tucson wells in the south Avra Valley.

III.C.3. Evaluation of Historical Conditions and "Calibration"

The hydrologic inventory analysis was used to evaluate groundwater conditions from about 1941 to 1999. Aquifer parameters for the sub-areas were developed from model parameters presented in the USGS WRI 90-4178. Specific yields were estimated based on review of Figure 13 of that report, while transmissivities were estimated based on review of Figures 8 (transmissivity in layer 2 of the USGS model) and 9 (pre-development transmissivity in layer 1 of the USGS model). The sum of these transmissivities was used in the hydrologic inventory analysis.

Estimates were prepared for the components of the historical hydrologic inventory. These components include:

- ♦ Recharge
  - Groundwater inflows from margins of the analysis area
  - Streamflow infiltration
  - Incidental recharge

- ♦ Discharge
  - Groundwater outflows from margins of the analysis area
  - Groundwater pumping

Information from the USGS modeling study was used to estimate these components for the 1940 to 1985 period covered by the USGS study. For later years, the components were estimated through review of other published sources, including records of the AMA and data presented in the management plans for the Tucson AMA.

Groundwater level hydrographs were prepared to compare groundwater levels estimated using the hydrologic inventory to observed groundwater levels and groundwater levels estimated using the USGS numerical groundwater model. The hydrologic inventory is able to reflect the large-scale trends in groundwater levels that have historically occurred.

Evaluation of the estimated historical groundwater levels also included a comparison of the flow pattern indicated by the results of the hydrologic inventory analysis to the observed flow pattern. The hydrologic inventory analysis showed essentially the same pattern of flow, with flow from south to north in Avra Valley toward the Santa Cruz River, and flow beneath the Santa Cruz River from the southeast to the northwest.

III.C.4. Analysis of Alternatives

The hydrologic inventory analysis was used to estimate the groundwater impacts for each alternative, where the impacts are defined as the difference between the groundwater conditions projected for a given alternative and the groundwater conditions projected for the No Action Alternative. The analysis for each alternative reflects estimated future demands, an assessment of the water supplies used to meet those demands, and consideration of recharge (both artificial and incidental).

The No Action Alternative serves as the basis of comparison to determine impacts for the other alternatives. The discussion of the No Action Alternative therefore focuses, to some extent, on absolute groundwater levels, while discussion of the Settlement and Non-Settlement Alternatives focuses on impacts (differences from the No Action Alternative).

III.C.4.a. No Action Alternative

Changes in groundwater levels, groundwater quality, and subsidence relative to the No Action Alternative are discussed in the sub-sections that follow.

III.C.4.a.(1). Groundwater Levels

Projected hydrographs of average annual groundwater levels for the No Action Alternative for each sub-area are shown on Figures I-28 through I-35. Projected levels for the other alternatives are also shown on those same figures and will be discussed later in the sections that address each of those alternatives. In addition to these hydrographs, Figure I-36 shows the change in the average groundwater elevations for each sub-area from 2001 to 2051 under the No Action Alternative.

As shown on Figure I-36, changes in groundwater levels during the 2001 to 2051 period in Avra Valley vary widely. The largest changes in groundwater levels occur in the southerly portion of the Avra Valley, with groundwater levels more than 300 feet higher than under the No Action

Alternative in the Avra Coop sub-area, and levels more than 150 deeper in the South Avra Valley sub-area.

Groundwater levels generally rise in the sub-areas which have direct recharge facilities (the Avra Coop, CMID Central, and CMID West sub-areas) or which receive CAP water for in-lieu recharge (the CMID West and North Avra Valley sub-areas). The groundwater levels reflect the amounts of recharge water available over time. In the Avra Coop sub-area, the rate of groundwater level rise increases after 2017, reflecting the assumption that the full recharge capacity would be phased in at that time.

The relatively large decline in groundwater levels in the South Avra Valley sub-area reflects the assumption in the analysis that the City of Tucson would utilize a well field in the South Avra Valley sub-area to help meet demands in the Tucson metropolitan area beginning in year 2017. The pumping is assumed to be equal to the direct recharge in the Avra Coop sub-area, less a five-percent “cut” to the aquifer.

Directions of groundwater flow in the Avra Valley in year 2051 estimated using the hydrologic inventory would be similar to current flow directions, except that the flow between the Avra Coop sub-area and the South Avra Valley sub-area would reverse. This flow reversal would result in the development of a groundwater level depression within the South Avra Valley sub-area.

III.C.4.a.(2). Water Quality

The general pattern of flow for the No Action Alternative would be similar to the existing flow pattern, with the exception of the flow reversal between the Avra Coop and South Avra Valley sub-areas. Changes in groundwater quality due to changes in the flow pattern would not be anticipated. While a groundwater level depression would form in the South Avra Valley sub-area, much of the groundwater pumped would be used outside of the sub-area, so that the development of an adverse salt balance would not be expected.

Bodies of poor quality water at depth were not identified in the Avra Valley. Therefore, potential groundwater quality impacts due to lowering of levels into a deeper zone of poor quality water are not anticipated.

The TDS concentration of CAP water being directly recharged is generally similar to the TDS concentration in the underlying groundwater. Therefore, substantial changes in groundwater quality due to direct recharge are not anticipated.

III.C.4.a.(3). Subsidence

Under the No Action Alternative, over the 2001 to 2051 period, groundwater levels were estimated to decline by a relatively small amount in the Picacho and Tortolita sub-areas (eight and 34 feet respectively), and substantially in the South Avra Valley sub-area (more than 150 feet). There would be the potential for subsidence in these sub-areas, and particularly in the South Avra Valley sub-area.

III.C.4.b. Impacts of the Settlement and Non-Settlement Alternatives

Changes in groundwater levels, groundwater quality, and subsidence relative to the No Action Alternative are discussed in the sub-sections which follow.

III.C.4.b.(1). Groundwater Levels

Projected hydrographs of average annual groundwater levels under the Settlement and Non-Settlement Alternatives for each sub-area were shown previously on Figures I-28 through I-35. Projected levels for the No Action Alternative are also shown on those same figures. In addition, the groundwater level impacts in year 2051 (i.e., difference in groundwater levels from the No Action groundwater levels) are shown in Figure I-37 (Settlement Alternative), Figure I-38 (Alternative 1), Figure I-39 (Alternative 2), Figure I-40 (Alternative 3A), and Figure I-41 (Alternative 3B).

Groundwater level impacts show up on the hydrographs as small divergences from the No Action Alternative groundwater levels. Impacts for all alternatives in all sub-areas are very small. In year 2051, the largest impact is a decrease in groundwater levels of 14 feet in the North Avra Valley sub-area under the Settlement Alternative and Non-Settlement Alternative 3B. Directions of groundwater flow in Avra Valley for the Settlement Alternative and all of the Non-Settlement Alternatives would remain the same as for the No Action Alternative.

While the impacts are very small in Avra Valley, an evaluation was made of those impacts for the Avra Coop sub-area (which contains Avra Coop) and the South Avra Valley sub-area (which contains the Schuk Toak District of the Tohono O'odham Nation). Impacts in the North Avra Valley sub-area were also considered, reflecting that this sub-area has the largest impacts, and is adjacent to the Avra Coop sub-area.

Figure I-42 presents a graphical comparison of groundwater level impacts in year 2051 for the North Avra Valley and Avra Coop sub-areas for the Settlement and Non-Settlement Alternatives. The Avra Coop receives CAP water in the Settlement Alternative and Non-Settlement Alternative 3B. However, the impact associated with this CAP water is masked by changes in groundwater underflow from the adjacent North Avra Valley sub-area and changes in direct recharge of M&I water in the Avra Coop sub-area.

The Schuk Toak District receives additional CAP water relative to the No Action Alternative under the Settlement Alternative, and Alternatives 2, 3A, and 3B. This CAP water results in higher groundwater levels for those alternatives than under the No Action Alternative, as shown on Figure I-43. Under Non-Settlement Alternative 1, in which the Schuk Toak District does not receive additional CAP water, the resulting groundwater level would be the same as for the No Action Alternative.

III.C.4.b.(2). Groundwater Quality

None of the alternatives result in substantial changes in gradients or the flow pattern relative to the No Action Alternative. Therefore, similar to the No Action Alternative, substantial changes in groundwater quality are not anticipated for any of these alternatives.

III.C.4.b.(3). Subsidence

Groundwater level changes under the Settlement Alternative and all Non-Settlement Alternatives would be similar to the No Action Alternative, so that the anticipated subsidence would also be similar. Specifically, there would be the potential for subsidence in the Picacho, Tortolita, and South Avra Valley sub-areas, and the potential subsidence in the South Avra Valley sub-area would be the most substantial.

III.D. Groundwater Level Analysis for the Pinal/Salt River Valley Area

A hydrologic inventory analysis was performed for groundwater in the basin fill materials in the Pinal and Salt River Valley areas. The study area considered for the Pinal/Salt River Valley areas and the sub-areas used in the analysis are shown on Figure I-44.

Major drainage features within the study area are the Gila, Salt, Agua Fria and Santa Cruz Rivers. Each of these rivers carries periodic flood flows and spills, and the Gila and Salt Rivers are perennial in some of their reaches. The Gila, Salt, and Agua Fria Rivers each have storage developed, in upstream reservoirs, which affects the flows in these rivers.

The lands considered in this study area have been extensively developed. Both the Salt River Valley and Pinal County areas had extensive historical development for irrigated agriculture, and there has been substantial urbanization of these lands, particularly in the Salt River Valley. The analysis for the Pinal and Salt River Valleys covers an extensive geographic area. In order to facilitate presentation of these results, they are discussed in the context of four general geographic areas (Pinal County, GRIC, East Salt River Valley, and West Salt River Valley). The sub-areas that comprise each of these geographic areas are shown on Figure I-45. The GRIC is centrally located between these areas, with Pinal County lands lying south of GRIC, East Salt River lands lying northeasterly of GRIC, and West Salt River lands lying northwesterly of GRIC.

III.D.1. Existing Groundwater Conditions

There are a number of studies that describe the existing and historical groundwater conditions in all or a portion of the study area. These studies, including studies prepared by the USBR, USGS, and ADWR, provided the basis for the discussion presented below.

III.D.1.a. Geology

The description of geology has been primarily based on discussion presented in the 1976 USBR study, *Geology and Groundwater Resources Report, Maricopa and Pinal Counties, Arizona*. Groundwater is contained in the basin fill materials that have been deposited between the essentially non-water-bearing igneous and metamorphic rocks of the adjacent mountain ranges. The basin fill, similar to that described for the Avra Valley and Tucson areas, can be divided into three units on the basis of lithology. These units (from the deepest to the most shallow unit) are commonly termed the “Lower Conglomerate Unit,” the “Middle Fine-Grained Unit,” and the “Upper Alluvial Unit.”

The Lower Conglomerate Unit was only briefly described in the USBR 1976 geology report, so this discussion primarily relies on information presented for the deeper materials presented in the ADWR Modeling Report No. 6. This unit consists of conglomerate and gravel at the basin margins, and grades into finer deposits toward the center of the basins. It typically ranges in thickness from a few hundred feet at the valley margins to thousands of feet in the central portions of the basins.

The Middle Fine-Grained Unit, which overlies the Lower Conglomerate Unit, was deposited in lacustrine or playa depositional environments. This unit generally consists of fine interbedded sands and silty clay in the upper portions, silt and clay with interbedded sands and re-worked evaporites in the middle portions, and evaporites with some clay and silt in the lower sections. This unit generally occurs in the central portions of the deeper alluvial basins and is often absent toward the margins of the basins. Within the study area, the Middle Fine-Grained Unit occurs in the central portions of the East and West Salt River Valley areas and the Eloy and Maricopa sub-basins of the Pinal area. It is generally absent from the margins of these areas, and may be absent beneath portions of GRIC. This unit tends to become thicker toward the central portion of the basins.

The Upper Alluvial Unit is the uppermost unit. It overlies the Middle Fine-Grained Unit (where present) or the Lower Conglomerate Unit. It is composed of unconsolidated alluvial materials, and these deposits may tend to become finer-grained toward the centers of the valleys and in the deeper portions of this unit. This unit is more uniform in thickness along both the margins and central portions of the basins, typically being about 200 to 400 feet thick.

The alluvial fill is relatively thin adjacent to the mountains, and these bedrock "highs" define distinct but interconnected groundwater basins. This includes the East and West Salt River Valley basins in the Phoenix area, and the Maricopa-Stanfield and Eloy sub-basins in the Pinal area. These sub-basins are recognized in ADWR's reports for the Phoenix and Pinal AMAs.

III.D.1.b. Groundwater Occurrence and Movement

Groundwater occurs under confined, semiconfined, and unconfined conditions within these deposits. Where present, the Middle Fine-Grained Unit often provides confinement to the deeper Lower Conglomerate Unit and to coarser deposits within the Middle Fine-Grained Unit. Groundwater in the Upper Unit can occur under "semi-confined" conditions in which the confining beds have limited lateral extent or are "leaky" and the groundwater behavior is intermediate between the confined and unconfined conditions. Typically, groundwater elevations in different levels of a semi-confined aquifer can differ vertically under pumping stresses but tend to return to approximately the same elevation over time after the pumping is stopped.

Under pre-development conditions, groundwater flow was generally from the mountain fronts toward the major drainages and along the major drainages paralleling the stream flows. This pattern of flow has changed over time in response to the development of irrigated agriculture and urbanization, which have substantially lowered groundwater elevations in many areas. Groundwater depressions have formed in the Eloy and Maricopa-Stanfield sub-basins in the

Pinal area, north and south of the Salt River in the East Salt River Valley area, and in the area north of the Gila River and west of the Agua Fria River in the West Salt River Valley area.

III.D.1.c. Groundwater Quality

Existing groundwater quality conditions were identified with respect to both general mineral constituents and for specific contaminants of interest.

III.D.1.c.(1). General Minerals

The TDS concentration is used as the general indicator of groundwater quality. The 1974 USGS Map I-845-G ("Dissolved-Solids Content of Ground Water in the Phoenix Area, Arizona") was used to define these conditions. Information on TDS was also reviewed from the TMP for the Phoenix AMA (Figure 7-3 of that document). Information on other general minerals as evaluated using USGS Map I-845-F ("Chemical Quality of Ground Water for Public Supply in the Phoenix Area, Arizona") and information from the Phoenix AMA.

For the southern portion of the Pinal County area, information was also reviewed from USGS Map I-844-I ("Dissolved-Solids Content of Ground Water in the Tucson Area, Arizona") and USGS Map I-844-L ("Map Showing Chemical Quality of Ground Water for Public Supply in the Tucson Area, Arizona"). Those maps presented information on the TDS, hardness of groundwater, and the distribution of fluoride and nitrate for the upper 300 feet of saturated aquifer in the 1965 to 1972 period.

The following discussion of general minerals has been organized by general geographic areas. Locations of each geographical area were previously shown on Figure I-45.

III.D.1.c.(1).(i). Pinal County Area

In the Maricopa-Stanfield sub-basin of the Pinal AMA, the USGS Map I-845-G shows the concentration of TDS generally decreases from the margins of the sub-basin (where TDS concentrations are generally from 500 to 1,000 ppm) to the center of the sub-basin (where TDS concentrations are generally less than 500 ppm). There is a similar pattern of TDS concentrations in the Eloy sub-basin of the Pinal AMA, with TDS concentrations of 500 to 1,000 ppm generally at the margins of the basin, and less than 500 ppm in the central portions of the basin. There are also some pockets with higher TDS concentrations (in the range of 1,000 to 3,000 ppm), including in the vicinity of Casa Grande, Coolidge, and the Picacho Reservoir area. The map of TDS measurements in the Pinal AMA TMP are generally consistent with this pattern, although it does often show higher TDS concentrations (almost one-half of the samples shown have a TDS concentration which exceeds 1,000 ppm) and higher TDS concentrations in the central portion of the Maricopa-Stanfield sub-area.

The USGS map I-845-G does show poorer quality water occurring at depth in parts of the Eloy sub-basin of the Pinal AMA, within the HIDD/SCIDD and CAIDD sub-areas. These poorer quality water zones can have TDS concentrations in excess of 3,000 ppm.

Relatively hard groundwater (hardness exceeding 150 ppm) is present beneath the northern portions of the Eloy sub-basin and the northeasterly portions of the Maricopa-Stanfield sub-basins. There are also several areas with relatively high fluoride concentrations (over 1.4 ppm), including the western and southwestern margins of the Maricopa-Stanfield sub-basin, lands adjacent to the Sacaton Mountains, and pockets in the vicinity of Arizona City and Coolidge. No areas were shown with nitrates exceeding 45 ppm.

III.D.1.c.(1).(ii). GRIC

The concentration of TDS in groundwater beneath GRIC generally increases from east to west. In the GRIC Sacaton, GRIC South Central, and the eastern portions of the GRIC East Central sub-areas, the TDS concentration generally ranges from about 500 to 1,000 ppm. Beneath most of the rest of GRIC, the TDS concentration is generally between 1,000 and 3,000 ppm, although there is also a band of groundwater which runs through the northerly part of the GRIC North Central, GRIC Komatke, and GRIC Maricopa Village sub-areas where the TDS concentration exceeds 3,000 ppm.

The USGS Map I-845-F shows that essentially all of the groundwater underlying GRIC is relatively hard, with hardness exceeding 150 ppm. There are also relatively high fluoride concentrations (over 1.4 ppm) beneath much of GRIC, specifically adjacent to the San Tan and Sacaton Mountains, and between the Sacaton and Sierra Estrella Mountains. No areas were shown with nitrates exceeding 45 ppm.

III.D.1.c.(1).(iii). East Salt River Valley

The concentration of TDS in groundwater beneath the East Salt River Valley generally increases in the direction of groundwater flow under pre-development conditions. Relatively low concentrations (below 500 ppm) are generally present in the Scottsdale North, McDowell, Superstition, Apache Junction, and East Mesa sub-areas. Somewhat higher concentrations (500 to 1,000 ppm) are generally present under the Salt River Indian, Scottsdale South, NMIDD, Florence Junction, QCID, and Williams Airport sub-areas. Relatively high concentrations (from 1,000 to 3,000 ppm) of TDS are present beneath the remainder of the East Salt River Valley.

The USGS Map I-845-F shows that most of the groundwater underlying the East Salt River Valley is relatively hard, with hardness exceeding 150 ppm. There is some relatively soft water (hardness less than 150 ppm) in the westerly portion of the Scottsdale North sub-area, the Apache Junction sub-area, and the eastern portions of the Florence Junction and Superstition sub-areas.

There are relatively high fluoride concentrations (over 1.4 ppm) in the northern portion of the East Mesa sub-area. The TMP for Phoenix shows some areas with relatively high nitrate concentrations (greater than maximum containment level of 45 ppm).

III.D.1.c.(1).(iv). West Salt River Valley

The concentration of TDS in groundwater beneath the West Salt River Valley generally increases in the direction of groundwater flow under pre-development conditions. Relatively low concentrations (below 500 ppm) are generally present in the northernmost areas, corresponding to the Sun City West, MWD, West Side M&I, and northern portions of the Glendale/Peoria sub-areas. Somewhat higher concentrations (500 to 1,000 ppm) are generally present in the central portions of the Glendale/Peoria, MWD, and West Side M&I sub-areas. Relatively high concentrations (from 1,000 to 3,000 ppm) of TDS are present beneath the remainder of the West Salt River Valley, with TDS concentrations exceeding 3,000 ppm in a band generally located along the Gila River below the confluence with the Agua Fria River. USGS Map I-845-G also indicates that the southern portion of the MWD and West Side M&I sub-areas may be underlain by more saline water (from 1,000 to over 3,000 ppm) at depths greater than about 500 to 700 feet. This poor quality water is associated with the Luke Salt Dome.

The USGS Map I-845-F shows that most of the groundwater underlying the West Salt River Valley is relatively hard, with hardness exceeding 150 ppm. There is some relatively soft water (hardness less than 150 ppm) in the northwestern portion of the area (corresponding to the MWD sub-area, and portions of the West Side M&I and Sun City West sub-areas).

There are relatively high fluoride concentrations (over 1.4 ppm) in several locations. Specifically, this includes a fringe along the northern and eastern margin of the North Phoenix sub-area, in the Avondale sub-area, in the southern portion of the MWD and West Side M&I sub-areas, and the East and West Buckeye sub-areas.

The USGS Map I-845-F showed much of the West Salt River Valley is underlain by groundwater with relatively high concentrations of nitrate (more than 45 ppm). This includes all or a portion of the lands in the South Phoenix, North Phoenix, Southwest Phoenix, Avondale, Glendale/Peoria, and East Buckeye sub-areas. The TMP for the Phoenix AMA also showed high nitrates being prevalent in the vicinity of the Gila River.

III.D.1.c.(2). Other Constituents

Other water quality constituents were considered with reference to information presented in the TMPs for the Phoenix and Pinal AMAs. Information in those documents included discussion for metals, volatile organic compounds, petroleum hydrocarbons, and pesticides. Maps are also included showing the locations and results of test analyses for metals, volatile organic compounds, and pesticides in the Phoenix AMA. The TMP also identifies several "specific contamination areas."

III.D.1.c.(2).(i). Pinal County Area

Only one water quality study area in Pinal County was identified in the Pinal AMA TMP. This is a chromium disposal site located about five miles northwest of Casa Grande.

III.D.1.c.(2).(ii) GRIC

No water quality study areas on GRIC were identified in either the Phoenix or Pinal AMA TMPs.

III.D.1.c.(2).(iii) East Salt River Valley

Water quality study areas identified in the Phoenix AMA TMP are mostly concentrated in the vicinity of the Salt River, in areas corresponding to the Williams Airport sub-area, West Mesa sub-area, Tempe North sub-area, and the Scottsdale South sub-area. These are the same areas that show high metals and volatile organic concentrations on the maps in the plan.

III.D.1.c.(2).(iv). West Salt River Valley

A number of the water quality study areas identified in the Phoenix AMA TMP are mostly concentrated in areas corresponding to the Phoenix South, Phoenix North, Phoenix Southwest, and the southeasterly portion of the Glendale/Peoria sub-areas. There are also some water quality study areas in the Avondale sub-area and the southerly portion of the West Side M&I sub-area. Areas with high concentrations of volatile organic compounds and pesticides generally occur in these same sub-areas. These are the same areas that show high metals and volatile organic concentrations on the maps in the plan.

III.D.1.d. Subsidence

Subsidence has occurred historically in a number of locations in both the Pinal area and the Salt River Valley. These areas, as identified in the TMPs for the Pinal and Phoenix AMAs and on a map prepared by the USGS (Map I-845-H, "Land Subsidence and Earth Fissures in Alluvial Deposits in the Phoenix Area, Arizona") include:

- **Luke Air Force Base Area.** In this location, subsidence has been as much as 17 feet and has affected an area of about 140 square miles. Earth fissures have also developed in this area in response to the subsidence. The area shown on USGS Map I-845-H generally corresponds to the MWD and West Side M&I sub-areas and relatively limited areas of the Sun City West and Glendale/Peoria sub-areas.

- **Queen Creek Area.** More than three feet of subsidence had occurred over an area of about 230 square miles in this area by 1977.

- **East Mesa Area.** This area has experienced over five feet of subsidence from 1948 to 1981. The USGS map shows that the areas of greatest subsidence in Mesa and Queen Creek are part of a larger area of subsidence. This subsidence likely includes portions of the Mesa West, Mesa East, Williams Airport, QCID, NMIDD, Chandler North, and Chandler South sub-areas.

- **Apache Junction Area.** This area has experienced over two to three feet of subsidence since the early 1970s. Earth fissures are also present in this area.

- **Central Scottsdale.** This area has subsided at least one-half foot.

- **Maricopa-Stanfield Sub-basin.** There has been substantial subsidence in the Maricopa-Stanfield sub-basin of the Pinal AMA. Subsidence of 11.8 feet was measured near Stanfield in 1977. There is also earth-fissuring present. The USGS map indicates that the subsidence is extensive in this area, including lands in both the MSIDD North and MSIDD South sub-areas.

- **Eloy Sub-basin.** There has been subsidence of more than 15 feet by 1985 south of Eloy. There are also extensive earth fissures in this area. The USGS map indicates subsidence is extensive within the CAIDD sub-area and extends into the HIDD sub-area.

As shown by this list, there are a number of areas identified as having historical subsidence. Most of these areas correspond to areas that have experienced substantial lowering of groundwater levels and/or the development of groundwater depressions (i.e., the Luke Cone area corresponding to the MWD and the West Side M&I sub-areas, the Queen Creek area (QCID sub-area), east Mesa area (East Mesa sub-area), central Scottsdale (Scottsdale South sub-area), and the Maricopa-Stanfield sub-area (MSIDD North sub-area)). Based on the widespread occurrence of subsidence and the similarity of geologic materials throughout this area, it is assumed that all of the sub-areas in the Pinal/Salt River Valley area have geologic conditions conducive to subsidence.

III.D.2. Evaluation of Historical Conditions and "Calibration"

The hydrologic inventory analysis was used to evaluate groundwater conditions from about 1910 to 1999. Estimates of aquifer transmissivities were primarily based on Plate 2 of USGS WSP 1860, which shows transmissivities used in the analog model developed by the USGS. While the transmissivities used are not the most recent evaluation of aquifer transmissivities (estimates could be made using hydraulic conductivity values in the models more recently developed by the ADWR for the Phoenix and Pinal AMAs), they provide reasonable values for the purpose of this analysis. Also, these values can be used more directly than the hydraulic conductivity values used in the ADWR models, in that the transmissivity can be determined directly from the plate, rather than computed based on hydraulic conductivity.

Aquifer storage characteristics were represented by specific yield values. For this analysis, specific yields were estimated by visual inspection of figures in the ADWR Model Report No. 8 for the Phoenix AMA groundwater model which show specific yields by model cells.

Estimates were prepared for the components of the historical hydrologic inventory. These components include:

- Recharge
  - Mountain front recharge
  - Groundwater inflows from margins of the analysis area
  - Streamflow infiltration
  - Incidental recharge

- ♦ Discharge
- Phreatophyte evapotranspiration
- Groundwater outflows from margins of the analysis area
- Groundwater pumping
- Discharges to springs

The components of the hydrologic inventory were estimated based on review of a number of sources, including modeling studies performed by the USGS (WSP 1860), modeling studies performed by ADWR for the Salt River Valley and the Pinal area, the hydrologic survey report prepared by ADWR for conditions on GRIC, records of the Pinal and Phoenix AMAs including the published management plans.

In evaluating the portfolio of supplies historically used, consideration was given to the sources of surface water supply available in the Pinal and Salt River Valley areas, which include supplies from the Salt, Gila, and Agua Fria Rivers, as well as from the CAP.

Groundwater level hydrographs were prepared to compare groundwater levels estimated using the hydrologic inventory to observed groundwater levels. In contrast to the comparisons discussed for the Avra Valley and Tucson areas, the historical groundwater levels are estimated average levels for sub-areas estimated by evaluation of historical groundwater level maps. A sample comparison hydrograph is presented on Figure 46 for the Scottsdale South sub-area. While there is not an ideal match, the comparison does indicate that the hydrologic inventory is able to reflect the large-scale trends in groundwater levels that have historically occurred.

Evaluation of the estimated historical groundwater levels also included a comparison of the flow pattern indicated by the results of the hydrologic inventory analysis to the observed flow pattern. The hydrologic inventory analysis showed changes in the groundwater flow pattern over time that corresponded reasonably well with historical conditions. In particular, groundwater level depressions are generally predicted by the hydrologic inventory in locations and timeframes that correspond with historical conditions.

III.D.3. Analysis of Alternatives

The hydrologic inventory analysis was used to estimate the groundwater impacts for each alternative, where the impacts are defined as the difference between the groundwater levels projected for a given alternative and the groundwater levels projected for the No Action Alternative. The analysis for each alternative reflects estimated future demands and an assessment of the water supplies used to meet those demands, as well as consideration of recharge (both artificial and incidental).

The No Action Alternative serves as the basis of comparison to determine impacts for the other alternatives, and therefore, focuses to some extent on absolute groundwater levels, while discussion of the Settlement and Non-Settlement Alternatives focuses on impacts (differences from the No Action Alternative).

III.D.3.a. No Action Alternative

The analysis for the Pinal and Salt River Valleys covers an extensive geographic area. In order to facilitate presentation of these results, they are discussed in the context of four general geographic areas (Pinal County, GRIC, East Salt River Valley, and West Salt River Valley). The sub-areas that comprise each of these geographic areas were shown previously on Figure I-45.

III.D.3.a.(1). Pinal County Area

Changes in groundwater levels, groundwater quality, and subsidence under the No Action Alternative are discussed in the sub-sections that follow.

III.D.3.a.(1).(i). Groundwater Levels

The projected average annual groundwater levels for the No Action Alternative for each sub-area are shown on Figures I-47 through I-52. Projected levels for the other alternatives are also shown on those same figures and will be discussed later in the section which addresses the Settlement and Non-Settlement Alternatives.

Groundwater levels decline from 2001 to 2051 throughout the Pinal County area, as shown on Figure I-53. These estimated declines range from 27 feet in the SCID sub-area to 77 feet in the HIDD/SCIDD sub-area. The declines largely result from continued reliance on groundwater to meet irrigation demands in Pinal County. The groundwater level declines are moderated by reductions in cropped acreage and the associated decrease in water demands.

While groundwater levels are projected to decline, the depth to groundwater would remain substantially above the 1,000-foot depth "floor" established in the Pinal AMA. Therefore, groundwater use is not curtailed in the Pinal AMA due to this institutional consideration.

One of the factors affecting the groundwater levels under the No Action Alternative is the availability of water for in-lieu recharge to MSIDD, CAIDD, and HIDD from the Recharge Pool. That water is only available to these districts until the year 2017. As shown on the hydrographs for the MSIDD North, MSIDD South, CAIDD, and HIDD/SCIDD sub-areas, groundwater levels are either stable or rising through year 2017 while the in-lieu recharge water is available. After year 2017, the loss of the in-lieu recharge water and associated increase in groundwater pumping results in groundwater level declines in all of these sub-areas.

The pattern of flow in the Pinal County area for year 2051 estimated using the hydrologic inventory would be similar to current conditions. A groundwater depression would remain beneath MSIDD (under the No Action Alternative, the MSIDD North and MSIDD South sub-areas would have the same estimated groundwater elevation so that both sub-areas define the groundwater depression). The MSIDD North and HIDD/SCIDD sub-areas would continue to receive groundwater inflow from the north from the GRIC South-Central and Sacaton sub-areas.

III.D.3.a.(1).(ii). Groundwater Quality

Major changes in groundwater quality in the Pinal County area would not be expected. This reflects consideration that the flow pattern is similar to the existing flow pattern, and CAP water is not being directly recharged.

Groundwater levels would decline in the HIDD/SCIDD and CAIDD sub-areas, indicating some potential to produce water from deeper bodies of high TDS water at some locations in those sub-areas.

The discussion of existing conditions indicates that there may be an existing trend of increasing TDS, possibly related to the influence of recharge derived from irrigation return flows. While not one of the mechanisms for water quality impact, this possible trend of increasing TDS might continue in the future due to the continued impact of irrigation return flows.

III.D.3.a.(1).(iii). Subsidence

There is the potential for subsidence in the Pinal County area under the No Action Alternative, reflecting that estimated groundwater levels decline over the 2001 to 2051 period in all of the Pinal County sub-areas. Based on the magnitude of the predicted declines and the historical occurrence of subsidence, this would be of particular concern for the following areas:

> **Maricopa-Stanfield Area**. This area has experienced substantial subsidence historically, and the groundwater level in the MSIDD North sub-area is projected to experience further declines by year 2051.
>
> **Eloy Sub-basin.** Estimated groundwater levels would decline by 68 feet in the CAIDD sub-area and by 77 feet in the HIDD sub-area. These declines, in an area that has historically experienced subsidence, indicate the potential for continued subsidence in the future.

III.D.3.a.(2). GRIC

Changes in groundwater levels, groundwater quality, and subsidence under the No Action Alternative, are discussed in the sub-sections that follow.

III.D.3.a.(2).(i). Groundwater Levels

The projected average annual groundwater levels for the No Action Alternative for each sub-area are shown on Figures I-54 through I-59. Projected levels for the other alternatives are also shown on those same figures and will be discussed later in the section that addresses the Settlement and Non-Settlement Alternatives.

Groundwater levels generally decline in the GRIC sub-areas from 2001 to 2051, as shown on Figure I-53. Changes in estimated groundwater levels are very small in the western portion of GRIC, with groundwater levels unchanged in the GRIC Maricopa Village sub-area and a rise in groundwater levels of one foot in the GRIC Komatke sub-area. Larger declines occur to the east, ranging from 12 feet in the GRIC South sub-area to 48 feet in the GRIC North sub-area. Under the No Action Alternative, additional lands would be developed for irrigated agriculture, and additional supplies would be provided to meet those demands. Based on the assumptions for this analysis, there would be a net recharge for GRIC absent consideration of groundwater underflows to adjacent areas. The declines in groundwater levels for GRIC appear to be a reflection of the groundwater level declines in the adjacent sub-areas.

The average hydrologic inventory for the GRIC area was also evaluated, prepared by combining the hydrologic inventory analyses for the various sub-areas, which comprise GRIC. This balance is shown on Table I-21, as is the corresponding average balance for the 1990 to 1999 period.

Under the No Action Alternative, there would be some changes in groundwater flow directions beneath GRIC by year 2051. Under the No Action Alternative in 2051, all the flow between GRIC and the East Salt River Valley would be from GRIC to the East Salt River Valley. Also, there would be some flow reversals, so that groundwater in 2051 would flow from the GRIC Komatke sub-area to the GRIC North and GRIC South sub-areas, and groundwater would flow from GRIC South to GRIC North.

III.D.3.a.(2).(ii). Groundwater Quality

Changes in groundwater quality on GRIC would not be expected. This reflects consideration that: (1) the flow pattern is not being greatly modified; (2) while groundwater levels are declining, there are not well defined bodies of groundwater of differing water quality which occur at depth; and (3) CAP water is not being directly recharged. It is noted that recharge of irrigation return flows might tend to add salts to groundwater, and thereby increase the TDS. While not one of the mechanisms for water quality impact, it is noted that this possible trend of increasing TDS might continue in the future due to the continued impact of irrigation return flows. However, in the case of GRIC, the continued outflow of groundwater (and associated salts) to the north and south would help to maintain the salt balance.

III.D.3.a.(2).(iii). Subsidence

There is the potential for subsidence on GRIC lands. This potential is greater in the eastern portion of GRIC, where the larger groundwater level declines from 2001 to 2051 occur.

III.D.3.a.(3). East Salt River Valley

Changes in groundwater levels, groundwater quality, and subsidence under the No Action Alternative are discussed in the sub-sections that follow.

III.D.3.a.(3).(i). Groundwater Levels

The projected average annual groundwater levels for the No Action Alternative for each sub-area are shown on Figures I-60 through I-75. Projected levels for the other alternatives are also shown on those same figures and will be discussed later in the section that addresses the Settlement and Non-Settlement Alternatives.

Changes in groundwater elevation in the East Salt River Valley vary widely, including increases and declines in groundwater levels in various locations as shown on Figure I-53.

The rise in groundwater levels in the Salt River Indian and Mesa West sub-areas largely reflect recharge in the Granite Reef Underground Storage Project(GRUSP) facilities. The magnitude of that recharge dominates other factors that may impact groundwater levels in those sub-areas. As shown on the hydrographs for those sub-areas, groundwater levels rise each year until the assumed shortage period that begins in year 2043. From year 2043 to year 2051, groundwater levels decline due to the elimination of recharge and increased pumping. The recharge in the Salt River Indian and Mesa West sub-areas also affects other sub-areas through changes in groundwater underflows. For example, the stable or rising groundwater levels shown on the hydrographs for the Scottsdale South and Mesa East sub-areas appear to reflect those groundwater flows.

The areas of the East Salt River Valley between the Salt River and GRIC (including the Tempe North, Tempe South, Chandler North, and Chandler South sub-areas) all show substantial declines in estimated groundwater levels over the 2001 to 2051 period, ranging from 123 to 154 feet. The hydrographs for these sub-areas are also similar, showing a relatively rapid decline in groundwater levels in the early years of the period, and a reduced rate of decline in later years. The declines in groundwater levels reflect continued reliance on groundwater to meet demands in these areas.

The Queen Creek sub-area shows an overall rise in groundwater levels over the 2001 to 2051 period. The hydrograph for this sub-area shows a number of inflection points, as the groundwater levels reflect the interplay of a number of factors in this particular sub-area, such as urbanization and changes in irrigated acreage due to economic considerations.

The New Magma sub-area experiences a rise in groundwater levels through year 2017. Groundwater levels are relatively stable through year 2043, reflecting continued availability of CAP water until the assumed shortage. Under the shortage conditions from 2043 to 2051, groundwater levels decline, as all the irrigation demands in those years would be met by pumping groundwater.

The Scottsdale North sub-area experiences groundwater declines over the entire 2001 to 2051 period. The total decline over the 2001 to 2051 period is about 147 feet.

There would be several changes in the flow pattern for the East Salt River Valley by year 2051. The rise in groundwater levels in the Scottsdale South and QCID sub-areas would eliminate the groundwater level depressions in these areas by 2051. A new groundwater depression would develop beneath the Tempe South sub-area. Recharge at GRUSP would result in a groundwater mound beneath the Salt River Indian sub-area, and flow would radiate out to the adjacent sub-areas in 2051. In fact, the mound is less pronounced in year 2051 due to the declines in groundwater levels in the Salt River Indian sub-area that occur during the shortage period.

III.D.3.a.(3).(ii). Groundwater Quality

There would be some changes in the groundwater flow pattern by year 2051. These changes include the development of a groundwater level depression in the Tempe South sub-area, which is located in an area with relatively high TDS concentrations. Existing groundwater level depressions in the QCID and Scottsdale South sub-areas would not be present (there would be outflow from the Scottsdale sub-area to the Tempe North sub-area, and outflow from the QCID sub-area to the Chandler South and Williams Airport sub-areas). The changes in flow directions would tend to inhibit the movement of water from areas with high TDS concentrations to areas with low TDS concentrations.

Direct recharge of CAP water at GRUSP would not be anticipated to cause changes in groundwater quality, because the TDS concentrations in CAP water is similar to the TDS concentration in the underlying groundwater.

Bodies of poor quality water at depth were not identified in this area. Therefore, there would not be anticipated potential water quality impacts due to lowering of groundwater levels into such bodies of groundwater.

III.D.3.a.(3).(iii). Subsidence

There is the potential for subsidence in the East Salt River Valley area in those sub-areas that experience declines in groundwater levels over the 2001 to 2051 period. Based on the magnitude of the predicted declines and the historical occurrence of subsidence, this would be of particular concern for the following areas:

- **Southwestern Portion of East Salt River Valley**. This area has historically experienced subsidence, and estimated groundwater level declines are projected to range from 123 to 154 feet in the Tempe North, Tempe South, Chandler North, and Chandler South sub-areas.

- **Apache Junction Area.** Groundwater levels under the No Action Alternative were estimated to drop by 72 feet in the Apache Junction sub-area from 2001 to 2051. This may result in subsidence impacts in this area, particularly as this area has historically experienced subsidence.

- **North Scottsdale Area.** While not an area with documented historical subsidence, the deposits in this area are probably similar to other areas which have historically experienced subsidence. The estimated 147-foot decline in the North Scottsdale sub-area could result in subsidence.

While most sub-areas experience declines in estimated groundwater levels, there are some sub-areas in which groundwater levels would rise. This includes areas with historical subsidence (such as the Queen Creek and Mesa East sub-areas). Based on these estimated groundwater level impacts, subsidence would not be expected in these areas.

III.D.3.a.(4). West Salt River Valley

Changes in groundwater levels, groundwater quality, and subsidence under the No Action Alternative are discussed in the sub-sections that follow.

III.D.3.a.(4).(i). Groundwater Levels

The projected average annual groundwater levels for the No Action Alternative for each sub-area are shown on Figures I-76 through I-85. Projected levels for the other alternatives are also shown on those same figures and will be discussed later in the section that addresses the Settlement and Non-Settlement Alternatives.

Changes in groundwater elevation in the West Salt River Valley include both increases and declines in groundwater levels in various locations, as shown on Figure I-53. Substantial declines are estimated for the eastern part of the West Salt River Valley (ranging from 160 to 295 feet in the Phoenix South and Phoenix North sub-areas). Large declines were also estimated in the vicinity of the existing Luke Cone groundwater level depression (ranging from 136 to 150 feet in the West Side M&I and MWD sub-areas).

The decline in groundwater levels in the Phoenix North sub-area reflects, at least in part, the assumption that population in areas of North Phoenix which are not underlain by recoverable groundwater would be supplied with groundwater pumped from the Phoenix North sub-area. It also reflects an assumption that groundwater would be pumped in preference to using other supplies available to Phoenix. This assumption may not be fully consistent with the City's present and future operations. However, because this same assumption is made for the other alternatives, the impacts of those alternatives should be correctly portrayed.

The substantial groundwater level declines from 2001 to 2051 in the West Side M&I and MWD sub-areas (corresponding to the existing Luke Cone groundwater level depression) reflect continued reliance on groundwater to meet much of the demands in these sub-areas. The hydrograph for the MWD sub-area shows a relatively rapid decline in groundwater levels until 2017. The rise in groundwater levels from 2017 to 2042 reflects the operation of future West-side direct recharge facilities. During the shortage period (after year 2042 to year 2051), groundwater levels again decline, reflecting that groundwater recharge would not occur during that period. The West-side M&I sub-area groundwater levels show similar trends.

Groundwater levels increase beneath the Salt and Gila River in the Avondale, Buckeye East, and Buckeye West sub-areas and only show a small decline (11 feet) in the Phoenix Southwest sub-area. Groundwater levels in these sub-areas are influenced by recharge in the Salt and Gila Rivers.

The groundwater level hydrograph for the Glendale/Peoria sub-area shows the influence of the direct recharge operations. The Glendale/Peoria sub-area shows a rise of more than 25 feet in groundwater levels during the early years. This rise is followed by a stabilization in groundwater levels through about year 2042, at which time groundwater levels decline in response to reduced direct recharge and increased groundwater pumping during shortage conditions.

There would be several changes from the present flow pattern by year 2051 under the No Action Alternative. This included development of groundwater level depressions in the North Phoenix and MWD sub-areas.

III.D.3.a.(4).(ii). Groundwater Quality

There are several potential changes in groundwater quality possible for the West Salt River Valley. Under the No Action Alternative, groundwater flow from south to north would continue from the poorer quality water along the Gila River (with relatively high TDS and nitrate concentrations) to areas with presently better quality water. This flow could eventually result in a decline in groundwater quality in the northerly sub-areas. This potential might be of particular significance in the Luke Cone area, where the persistence of a groundwater depression would tend to cause an adverse salt balance.

An adverse salt balance might also develop in the Phoenix North sub-area, due to the development of a groundwater level depression. However, the assumed use of a portion of the pumped water in northerly areas of Phoenix that do not have access to groundwater might tend to prevent the development of an adverse salt balance.

Direct recharge of CAP water in the Agua Fria and future West-side recharge facilities could result in groundwater quality impacts. Concentrations of TDS in the CAP water are higher than TDS concentrations in the underlying groundwater. Recharge of CAP water could, therefore, eventually result in higher TDS concentrations in the underlying groundwater.

The quality of groundwater in the Luke Cone area (corresponding to the MWD and West-side M&I sub-areas) might also decline due to the lowering of groundwater levels into the deeper body of relatively poor quality water (with TDS concentrations in the range of 1,000 to 3,000 ppm).

III.D.3.a.(4).(iii). Subsidence

There is the potential for subsidence at some locations in the West Salt River Valley under the No Action Alternative. This potential would be of particular concern for the following areas which have relatively large groundwater level declines and which have historically experienced subsidence:

- **Phoenix Area**. While not identified as an area of substantial historical subsidence, the relatively substantial drop in groundwater levels projected for the North Phoenix sub-area (295 feet) and the South Phoenix sub-area (160 feet) would have the potential to result in subsidence in this area. As noted earlier in the section discussing groundwater level impacts, these groundwater level declines result in part from assumptions on the City of Phoenix use and distribution of non-CAP surface water.

- **Luke Cone Area**. This area has experienced historical subsidence, and the substantial drop of estimated groundwater levels (from 132 to 149 feet for the West-side M&I and MWD sub-areas) could result in continued subsidence.

III.D.3.b. Impacts of the Settlement and Non-Settlement Alternative

The analysis for the Pinal and Salt River Valleys covers an extensive geographic area. In order to facilitate presentation of these results, they are discussed in the context of four general geographic areas (Pinal County, GRIC, East Salt River Valley, and West Salt River Valley). The sub-areas that comprise each of these geographic areas were shown previously on Figure I-45.

III.D.3.b.(1). Pinal County Area

Changes in groundwater levels, groundwater quality, and subsidence under the Settlement and Non-Settlement Alternatives are discussed in the sub-sections that follow.

III.D.3.b.(1).(i). Groundwater Levels

Projected average annual groundwater level hydrographs under the Settlement and Non-Settlement Alternatives were shown previously on Figure I-47 through I-52. The hydrographs show how groundwater levels within a sub-area vary over the 50-year period. Projected levels for the No Action Alternative are also shown on those same figures. The geographical distribution of the groundwater level impacts between sub-areas in year 2051 (i.e., difference in groundwater levels from the No Action Alternative) are shown for the alternatives on Figure I-86 (Settlement Alternative), Figure I-87 (Alternative 1), Figure I-88 (Alternative 2), Figure I-89 (Alternative 3A), and Figure I-90 (Alternative 3B).

Groundwater level impacts in Pinal County for all of the alternatives are relatively small, with the greatest impact under any alternative being a rise of 29 feet in the HIDD/SCIDD sub-area under the Settlement Alternative. A comparison of groundwater level impacts in year 2051 for all sub-areas and all alternatives is presented in Figure I-91.

The groundwater level impacts in the Pinal area reflect those factors that influence the availability of CAP water to agricultural entities. Because water for in-lieu recharge is only available to entities in Pinal County through the year 2017, variations in the availability of recharge water between alternatives has a more limited influence than for entities in other areas that continue to receive in-lieu recharge water. The hydrographs for the MSIDD North, MSIDD South, CAIDD, and HIDD/SCIDD sub-areas (i.e., sub-areas which include entities that receive in-lieu recharge water) for all alternatives show an inflection in year 2017 for all alternatives, with declining groundwater levels after year 2017.

Because the magnitudes of the groundwater level impacts are relatively small, changes in groundwater underflow can exert a significant influence on the relative impacts for a given sub-area between the various alternatives. The discussion that follows focuses on the larger groundwater level impacts.

The groundwater level impacts between alternatives generally tend to follow the trends in the availability of CAP water from the Ag Pool and under NIA allocations, as shown on Figure I-91. The largest positive groundwater level impacts for the MSIDD North, MSIDD South, and CAIDD sub-areas are for Alternative 3A (in which NIA entities receive allocations), while the largest negative groundwater level impacts occur under Alternative 3B, in which there is the smallest availability of water for NIA. While the Settlement Alternative has the greatest total volume of CAP water available to agricultural users from the Ag Pool and Ag allocations, MSIDD and CAIDD receive a smaller proportion of the available water than under the Non-Settlement Alternatives, so that Alternative 3A provides more CAP water for these particular districts. Impacts for the other alternatives tend to be very small, and can be highly influenced by changes in groundwater flow from adjacent areas.

Changes in the availability of CAP water to SCIDD reflect factors that are unique to SCIDD. This results in a pattern of groundwater level impacts in the SCIDD and HIDD/SCIDD sub-areas (which contain a substantial proportion of the irrigated acres in SCIDD) which are distinct from those observed in other Pinal sub-areas. These same patterns also appear in the groundwater level impacts for the Casa Grande area, which also contains some lands in SCIDD. SCIDD only gets water from the Ag Pool under the Settlement Alternative. This provides an additional increment of surface water to SCIDD under the Settlement Alternative, which in turn tends to improve the groundwater levels in the SCIDD, HIDD/SCIDD, and Casa Grande sub-areas for this alternative. For example, the Settlement Alternative is the only alternative in which the year 2051 groundwater levels in the SCIDD and HIDD/SCIDD sub-areas are higher than under the No Action Alternative.

The pattern of groundwater flow in the Pinal County area in year 2051 was evaluated for each alternative based on groundwater levels estimated using the hydrologic inventory analysis. The pattern for the Settlement and Non-Settlement Alternatives are similar to the No Action Alternative. A groundwater level depression would remain under MSIDD (although under some alternatives, it shifts from the MSIDD North to MSIDD South). No flow reversals occur, except between the MSIDD North and MSIDD South sub-areas if the location of the pumping depression shifts.

III.D.3.b.(1).(ii). Groundwater Quality

Changes in 2051 groundwater levels relative to No Action Alternative levels in the Pinal County area are generally small (less than 25 feet) for all alternatives and all sub-areas. The one exception is the 29-foot rise in the 2051 groundwater level relative to the No Action Alternative in the HIDD/SCIDD sub-area. The pattern of groundwater flow in year 2051 for the Settlement and all Non-Settlement Alternatives is similar to the pattern of flow under the No Action Alternative. Groundwater quality impacts would not be anticipated for these small changes in groundwater levels.

III.D.3.b.(1).(iii). Subsidence

The Settlement and Non-Settlement Alternatives result in relatively small impacts in all sub-areas in Pinal County. These groundwater level impacts would not be anticipated to result in substantial changes in the subsidence potential relative to the No Action Alternative

III.D.3.b.(2). GRIC

Changes in groundwater levels, groundwater quality, and subsidence under the Settlement and Non-Settlement Alternatives are discussed in the sub-sections that follow.

III.D.3.b.(2).(i). Groundwater Levels

Projected average annual groundwater level hydrographs under the Settlement and Non-Settlement Alternatives were shown previously on Figure I-54 through I-59. The hydrographs show how groundwater levels within a sub-area vary over the 50-year period. Projected levels for the No Action Alternative are also shown on those same figures. The geographical distribution of the groundwater level impacts between sub-areas in year 2051 (i.e., difference in groundwater levels from the No Action Alternative) are shown for the alternatives on Figure I-86 (Settlement Alternative), Figure I-87 (Alternative 1), Figure I-88 (Alternative 2), Figure I-89 (Alternative 3A), and Figure I-90 (Alternative 3B).

Groundwater level impacts in GRIC sub-areas reflect a number of factors that vary for each alternative. These factors include the amount and priority of CAP water allocated to GRIC, the total acres developed for irrigation and the buildout schedule for those acres, the assumed proportion of the demands which are met with groundwater, and changes in underflow between sub-areas. In interpreting results, it should be noted that there are differences in cropped acres between alternatives. The acreage differences include consideration that lands would be fallowed under some alternatives during shortage conditions.

Groundwater levels in three of the GRIC sub-areas (GRIC East, GRIC Komatke, and GRIC Maricopa Village) are influenced strongly by interactions with the Gila River and potential phreatophyte consumption, which tend to reduce the impacts in these sub-areas. The hydrographs for each of these sub-areas show that groundwater levels for several of the alternatives tend to approximately stabilize at a constant elevation, which is the assumed 25-foot depth that phreatophytes could reach to draw water. For this reason, the discussion in this section focuses on the larger groundwater level impacts in the GRIC Sacaton, GRIC North, and GRIC South sub-areas.

In order to aid the evaluation of impacts for GRIC, the average components of the hydrologic inventory for the GRIC area as a whole over the 50-year period were summarized in Table I-21 for each alternative. The bottom of the table shows the difference in the net pumping (groundwater pumping less incidental recharge) for the Settlement and Non-Settlement Alternatives relative to the No Action Alternative. The net pumping number reflects the various differences in the alternatives (such as cropped acreage and differences in CAP supplies and groundwater pumping). Differences in net pumping explain much of the difference in groundwater level impacts in year 2051 for the alternatives, as shown on Figure I-92. Smaller differences between alternatives and between the different sub-areas for a given alternative appear to reflect differences in groundwater flows from areas adjacent to GRIC.

The Settlement Alternative is the only alternative in which the net pumping is negative (pumping exceeds incidental recharge by about 29,000 afa), and the relatively large negative groundwater level impacts reflect this. The relatively small impact in the GRIC Sacaton sub-area may reflect higher groundwater levels (relative to the No Action Alternative) in the HIDD/SCIDD sub-area located south of the GRIC Sacaton sub-area.

Alternative 3A and Alternative 3B have a positive average annual net pumping of about 10,000 afa. There are negative groundwater level impacts for these alternatives, but these impacts are less negative than for the Settlement Alternative. The particularly small negative impact for the GRIC South sub-area under Alternative 3A appears to reflect the influence of the positive groundwater level impact in the MSIDD South sub-area on groundwater outflow from the GRIC South sub-area.

Alternatives 1 and 2 have the largest positive average annual net pumping (from about 34,000 afa under Non-Settlement Alternative 2 to about 40,000 afa under Non-Settlement Alternative 1). The resulting groundwater level impacts are slightly positive for Non-Settlement Alternative 1 and slightly negative for Non-Settlement Alternative 2.

The pattern of groundwater flow beneath GRIC in year 2051 was evaluated for each alternative based on groundwater levels estimated using the hydrologic inventory analysis. The pattern for the Settlement and Non-Settlement Alternatives are similar to the No Action Alternative. Flow directions between GRIC and neighboring areas would generally remain similar to the No Action Alternative, except that under the Settlement Alternative and Non-Settlement Alternative 3B, groundwater flow would be from the Chandler South sub-area to the GRIC North sub-area. Within GRIC, there is a flow reversal between the GRIC Komatke and GRIC South sub-areas under Alternative 1 (with flow from GRIC South to GRIC Komatke for this alternative).

III.D.3.b.(2).(ii). Groundwater Quality

Changes in groundwater quality on GRIC would not be expected for the Settlement and Non-Settlement Alternatives. This reflects consideration that: (1) the flow pattern is not being greatly modified; (2) while groundwater levels are declining, there are not well defined bodies of groundwater of differing water quality which occur at depth; and (3) CAP water is not being directly recharged. It is noted that recharge of irrigation return flows might tend to add salts to groundwater, and thereby increase the TDS. While not one of the mechanisms for water quality impact, it is noted that this possible trend of increasing TDS might continue in the future due to the continued impact of irrigation return flows. However, in the case of GRIC the continued outflow of groundwater (and associated salts) to the north and south would help to maintain the salt balance.

III.D.3.b.(2).(iii). Subsidence

There is the potential for subsidence on GRIC lands for all of the alternatives, and particularly for the easterly portions of GRIC. With the exception of Non-Settlement Alternative 1, this potential is greater than under the No Action Alternative.

III.D.3.b.(3). East Salt River Valley

Changes in groundwater levels, groundwater quality, and subsidence under the Settlement and Non-Settlement Alternatives are discussed in the sub-sections that follow.

III.D.3.b.(3).(i). Groundwater Levels

Projected average annual groundwater level hydrographs under the Settlement and Non-Settlement Alternatives were shown previously on Figure I-60 through I-75. The hydrographs show how groundwater levels within a sub-area vary over the 50-year period. Projected levels for the No Action Alternative are also shown on those same figures. The geographical distribution of the groundwater level impacts between sub-areas in year 2051 (i.e., difference in groundwater levels from the No Action Alternative) are shown for the alternatives on Figure I-86 (Settlement Alternative), Figure I-87 (Alternative 1), Figure I-88 (Alternative 2), Figure I-89 (Alternative 3A), and Figure I-90 (Alternative 3B).

Groundwater level impacts in the East Salt River Valley reflect different influences in different locations of the analysis. The discussion of these impacts in this section has been structured to discuss impacts on the basis of the primary factors that cause those impacts. This discussion also focuses on sub-areas that have relatively large groundwater level impacts.

The groundwater level impacts in the Salt River Indian, West Mesa, East Mesa, Tempe North, Chandler South, and Tempe South sub-areas appear to be closely related to recharge. Figure I-93 shows the groundwater level impacts in year 2051 for these sub-areas by alternative, compared to the reduction (relative to the No Action Alternative) in the availability of recharge water. As shown, the groundwater level impacts for the Non-Settlement Alternatives appear to reflect changes in available recharge water. The magnitude of the impact tends to decrease with increasing distance from the GRUSP facilities (which recharge the Salt River Indian and West Mesa sub-areas). Also, the pattern of groundwater level impacts in GRIC are similar (see Figure I-92), so that the impacts in some sub-areas reflect changes in groundwater flow from sub-areas influenced by both GRUSP and GRIC. Some of the differences between the various alternatives can also be seen on the hydrographs. For example, the hydrograph for the Salt River Indian sub-area reflects that recharge amounts are similar for all alternatives in the early years of the period, and that the CAP water available for recharge is reduced at different times under each alternative.

The groundwater levels for the Settlement Alternative are not as closely related to the reduction in the recharge pool. Specifically, while the Settlement Alternative has the greatest reduction in the recharge pool, there are relatively small groundwater level impacts (less than 15 feet) as shown on Figure I-93. These impacts reflect that under the Settlement Alternative, the cities of Mesa and Chandler would receive additional CAP water from GRIC in exchange for effluent that would otherwise be unused. Without that additional CAP supply, the largest negative groundwater level impacts would have been expected for the Settlement Alternative.

Groundwater level impacts in year 2051 for the QCID and NMIDD sub-areas are shown for all alternatives on Figure I-94. Both of these sub-areas have similar impacts, with relatively large negative groundwater level impacts under the Settlement Alternative and Non-Settlement

Alternatives 2, 3A, and 3B, and relatively small impacts under Non-Settlement Alternative 1. However, while the year 2051 impacts for the various alternatives are similar for both sub-areas, the impacts at other times during the 2001 to 2051 period can differ significantly, as shown on the hydrographs for those sub-areas.

The pattern of groundwater flow in the East Salt River Valley in year 2051 was evaluated for each alternative based on groundwater levels estimated using the hydrologic inventory analysis. The pattern for the Settlement and Non-Settlement Alternatives are generally similar to the No Action Alternative. The primary difference is that, in addition to the groundwater level depression which develops in the Tempe South sub-area for all alternatives, a groundwater level depression also develops beneath the Chandler South sub-area under Non-Settlement Alternative 2. Also, the QCID sub-area would remain as a groundwater level depression under the Settlement Alternative.

III.D.3.b.(3).(ii). Groundwater Quality

Water quality impacts due to lowering of groundwater levels into deeper poor quality zones are not anticipated, because bodies of poor quality groundwater at depth were not identified in the East Salt River Valley.

The pattern of groundwater flow in year 2051 for the Settlement and Non-Settlement Alternatives are generally similar to the pattern of flow under the No Action Alternative. The exception is that a groundwater level depression develops in the Chandler South sub-area under Non-Settlement Alternative 2 and a groundwater level depression would remain in the QCID sub-area under the Settlement Alternative. Groundwater quality impacts would not be anticipated for the generally small changes in groundwater flow patterns relative to the No Action Alternative flow pattern. Because groundwater is already of relatively poor quality in the Tempe South and Chandler South sub-areas (i.e., where groundwater level depressions develop), impacts are not anticipated due to the development of an adverse salt balance. There would be some potential for adverse water quality impacts in the QCID sub-area for the Settlement Alternative, related to the groundwater level depression under that alternative.

Direct recharge of CAP water at GRUSP would also not be anticipated to result in substantial impacts to groundwater quality. The TDS concentration of CAP water (about 500 to 750 ppm) is similar to the TDS concentration of the underlying groundwater.

III.D.3.b.(3).(iii). Subsidence

The Settlement Alternative and all Non-Settlement Alternatives result in both positive and negative estimated groundwater level impacts for sub-areas. The following sub-areas would experience relatively large changes in the potential for subsidence.

The largest groundwater level impacts generally occur in NMIDD and QCID. Substantial subsidence potential was not identified for these sub-areas under the No Action Alternative. However, groundwater level declines would occur for the Settlement and all Non-Settlement Alternatives in the NMIDD sub-area, indicating the potential for subsidence. In the QCID sub-area, groundwater levels would decline from present levels under the Settlement Alternative, and Non-Settlement Alternatives 2 and 3A. There would be the potential for subsidence under those alternatives.

In general, the Settlement and Non-Settlement Alternatives result in estimated groundwater levels in the vicinity of GRUSP and in the southwestern portion of the East Salt River Valley (i.e., the Tempe North, Tempe South, Chandler North, and Chandler South sub-areas) which are lower than under the No Action Alternative. In particular, estimated groundwater levels are lower than the No Action Alternative under the Settlement Alternative and Non-Settlement Alternatives 3A and 3B. In the southwestern portion of the East Salt River Valley, these groundwater level impacts could result in greater potential for subsidence. However, in the vicinity of GRUSP, year 2051 groundwater levels are still generally higher than year 2001 groundwater levels, so that subsidence impacts would not be anticipated in this area.

Groundwater levels in the Apache Junction and North Scottsdale sub-areas under the Settlement Alternative and Non-Settlement Alternative would be similar to levels under the No Action Alternative. There would be substantial potential for subsidence in both of these sub-areas under all alternatives.

III.D.3.b.(4). West Salt River Valley

Changes in groundwater levels, groundwater quality, and subsidence under the Settlement and Non-Settlement Alternatives are discussed in the sub-sections that follow.

III.D.3.b.(4).(i). Groundwater Levels

Projected average annual groundwater level hydrographs under the Settlement and Non-Settlement Alternatives were shown previously on Figure I-76 through I-85. The hydrographs show how groundwater levels within a sub-area vary over the 50-year period. Projected levels for the No Action Alternative are also shown on those same figures. The geographical distribution of the groundwater level impacts between sub-areas in year 2051 (i.e., difference in groundwater levels from the No Action Alternative) are shown for the alternatives on Figure I-86 (Settlement Alternative), Figure I-87 (Alternative 1), Figure I-88 (Alternative 2), Figure I-89 (Alternative 3A), and Figure I-90 (Alternative 3B).

Groundwater level impacts in the West Salt River Valley reflect relatively small impacts associated with additional allocation of CAP water and additional leases of CAP water to M&I entities, and relatively large impacts associated with direct recharge.

Figure I-95 presents groundwater level impacts in year 2051 for selected sub-areas in the West Salt River Valley area. It provides a means to readily compare the impacts for the various alternatives. The selected sub-areas were those that showed an impact of 25 feet or more for at least one of the alternatives. These sub-areas are particularly influenced by recharge, with direct recharge facilities located within each of these sub-areas. The groundwater level impacts for each of these sub-areas track with the changes in water available for recharge (which are also shown on Figure I-95). For example, the greatest reduction in recharge water occurs under the Settlement Alternative, which also has the largest negative groundwater level impacts.

Some of the differences between the various alternatives can also be seen on the hydrographs. For example, the hydrograph for the Glendale/Peoria sub-area reflects that recharge amounts are similar for all alternatives in the early years of the period, and that the CAP water available for recharge experiences reductions at different times for each alternative. The hydrographs for the MWD and the West-side M&I sub-areas (which also include direct recharge facilities that begin operation in 2017) also reflect changes in the availability of CAP water for recharge and in the assumed build-up of recharge capacity.

The pattern of groundwater flow in the West Salt River Valley in year 2051 was evaluated for each alternative based on groundwater levels estimated using the hydrologic inventory analysis. The groundwater flow patterns for the Settlement and Non-Settlement Alternatives are generally similar to the No Action Alternative. All alternatives result in groundwater level depressions in the MWD and Phoenix North sub-areas by year 2051, and all alternatives have groundwater flow from beneath the Salt and Gila Rivers to the more northerly areas of the West Salt River Valley.

III.D.3.b.(4).(ii). Groundwater Quality

Changes in 2051 groundwater levels relative to No Action Alternative levels in the West Salt River Valley vary in different locations. Groundwater level declines relative to the No Action Alternative are as much as almost 70 feet in the MWD sub-area under the Settlement Alternative. The groundwater level declines in the West-side M&I sub-area and the MWD sub-area could result in increased TDS concentrations in wells in the southern portions of those sub-areas, due to lowering of water in the vicinity of the "Luke Salt Dome," where poorer quality water is present at depth.

The patterns of groundwater flow in year 2051 for the Settlement and Non-Settlement Alternatives are generally similar to the pattern of flow under the No Action Alternative. Therefore, groundwater quality impacts relative to the No Action Alternative would not be anticipated due to changes in the flow pattern.

Changes in the volume of direct recharge of CAP water at the Agua Fria and future West-side recharge facilities could result in changes in groundwater quality. All of the action alternatives would result in reduced recharge of CAP water. That reduced recharge would lessen the potential degradation to the underlying groundwater that would occur under the No Action Alternative, due to the greater TDS concentration in CAP water.

III.D.3.b.(4).(iii). Subsidence

Estimated groundwater levels for the northwestern portion of the West Salt River Valley area (generally including the Glendale/Peoria, West-side M&I, and MWD sub-areas) generally show lower groundwater levels under the Settlement and Non-Settlement Alternatives than under the No Action Alternative. These impacts are relatively small under Non-Settlement Alternatives 1 and 2, and are relatively large under the Settlement Alternative and Non-Settlement Alternatives 3A and 3B. These groundwater level impacts indicate the potential for additional subsidence in these areas under the Settlement and Non-Settlement Alternatives.

III.E. Groundwater Level Analysis for the San Carlos Apache Area

The potential impacts of the CAP reallocation on the SC Apache Tribe were evaluated primarily on the basis of information presented in USGS WRI 89-4152. In comparison with many of the other areas considered in the reallocation analysis (such as the Tucson, Avra Valley, Pinal County, and Salt River Valley areas), there are relatively limited data available, and the analysis is, therefore, dependent on a greater degree of judgment.

A hydrologic inventory analysis was performed for the SC Apache Tribe area, shown on Figure I-96. Impacts on groundwater contained in the basin fill materials associated with the San Carlos and Gila Rivers on the SC Apache Tribe lands, located upstream of the San Carlos Reservoir, were evaluated.

III.E.1. Existing Groundwater Conditions

Because it is assumed that the CAP water allocated to the SC Apache Tribe is used to develop lands along the Gila and San Carlos Rivers, the groundwater resources evaluation focuses on this area of the Reservation. The Gila River is perennial during most years, while the San Carlos River is dry for at least part of most years.

Groundwater is currently used on the SC Apache Reservation for domestic uses and to supply a portion of the irrigation requirements. Most of the large capacity wells are completed in the stream alluvium and the upper portions of the basin fill materials, and such wells can produce more than 900 gallons per minute (gpm).

III.E.1.a. Geology

Rocks occurring on the Reservation in the vicinity of the Gila and San Carlos Rivers include mountains composed of igneous, metamorphic, and sedimentary rocks. The Gila and San Carlos Rivers are underlain by alluvial materials, generally of Tertiary and Quaternary age. Of primary interest for this study are the "Tertiary and Quaternary Basin Fill" and the "Quaternary Stream Alluvium."

III.E.1.a.(1) Tertiary and Quaternary Basin Fill

The Tertiary and Quaternary basin fill materials overlie consolidated rocks. The upper few hundred feet of these deposits consist of fine sand, silt, limestone and clay, with interbedded volcanic tuff deposits. These materials occur in well-bedded, but laterally discontinuous, layers. On the Reservation, the basin fill may be more than 3,200 feet deep.

III.E.1.a.(2). Quaternary Stream Alluvium

The Quaternary stream alluvium overlies the Tertiary and Quaternary fill materials along the Gila and San Carlos Rivers. It consists of poorly sorted sandy gravel and gravelly muddy sand. These materials are up to about 85 feet thick along the Gila River, and occur in the 4,000 to 8,000-foot wide river channel. For the San Carlos River, these materials are generally about 60 to 80 feet thick and occur in channel deposits about 1,200 to 4,900 feet wide.

III.E.1.b. Groundwater Occurrence and Movement

Groundwater occurs in the stream alluvium and the basin fill materials. The saturated thickness of the stream alluvium is about 30 to 40 feet beneath the Gila River and about 40 to 65 feet beneath the San Carlos River. This groundwater likely occurs under unconfined conditions.

Groundwater in the basin fill occurs under both confined and unconfined conditions. The unconfined conditions tend to occur at the margins of these materials, and the groundwater becomes confined toward the axis of the valleys.

Groundwater flow in the stream alluvium beneath the Gila and San Carlos Rivers generally parallels the flow in the associated river, with flow toward the San Carlos Reservoir at the western end of the Reservation.

Groundwater in the basin fill associated with the Gila River generally flows from the margins of the valleys, where it is recharged by percolation along the mountain fronts, toward the center of the valley. The groundwater levels in the basin fill beneath the river are higher than the levels in the overlying stream alluvium and indicate an upward flow of groundwater from the basin fill to the stream alluvium. While this pattern of flow is not explicitly discussed in USGS WRI 89-4152 for the San Carlos River, it is considered likely that the same flow pattern occurs at that location.

Transmissivity for the stream alluvium along the Gila River is estimated in the USGS report to be about 9,800 square feet per day from a flood wave propagation analysis, and about 28,000 square feet per day from an aquifer test. Transmissivity for the stream alluvium beneath the San Carlos River near Peridot was estimated to be about 19,000 square feet per day based on an aquifer test. The specific yield of the alluvium was estimated to be about 15 percent.

The specific yield of the basin fill of 10 percent was used for volume calculations presented in USGS WRI 89-4152. Limited data available on aquifer transmissivities indicate that transmissivity is significantly lower in the basin fill materials than in the stream alluvium, with observed values ranging from about 1,200 to 2,500 square feet per day.

III.E.1.c. Groundwater Quality

The existing groundwater quality conditions were evaluated by reference to material presented in the USGS Water Resources Investigation 89-4152, "Geology and Ground-Water Resources of the San Carlos Indian Reservation, Gila, Graham, and Pinal Counties, Arizona. Those data primarily addressed the general mineral constituents, and discussion in this section is restricted to TDS.

The quality of groundwater varies between the stream alluvium and basin fill associated with the Gila and San Carlos Rivers. Groundwater in the deposits associated with the Gila River generally has a TDS concentration greater than 500 ppm, and some wells adjacent to the Gila River produce water that contains more than 4,000 ppm of TDS. Those high TDS values were attributed to inflow of high TDS water from the underlying basin fill, percolation of irrigation return flows with high TDS, and concentration of TDS (salts) by use of groundwater by phreatophytes. The TDS concentration of water in wells in the basin fill deposits at least two miles from the Gila River and in silt and sand materials were about 240 to 380 ppm, while groundwater in basin fill adjacent to the Gila River contains from 370 to 2,570 ppm of TDS.

Groundwater in stream alluvium and the upper portions of the basin fill beneath the San Carlos River generally contains less than 500 ppm of TDS.

III.E.1.d. Subsidence

Information on historical subsidence on SC Apache Tribe lands was not located. The occurrence of clay materials in the basin fill does indicate that there may be the potential for subsidence if groundwater levels are lowered substantially.

III.E.2. Details of Analysis Methodology

USGS WRI-89-4152 does not present information that readily supports the development of a quantified hydrologic inventory from the SC Apache Tribe lands. It does indicate that components of the hydrologic inventory include:

- Recharge
  - Mountain front recharge
  - Recharge from streams
  - Irrigation return flows

- Discharge
  - Phreatophyte consumptive use
  - Groundwater pumping

Also, it is indicated that groundwater levels on the Reservation generally do not demonstrate either rising or falling groundwater trends, although the information does not appear to be definitive. While the information is limited, it appears to be most consistent with the groundwater on the SC Apache Tribe lands remaining within the safe yield under the demands present at the time of the USGS study. This information is also consistent with the limited level of development at present.

The mechanism for the SC Apache Tribe to receive CAP water would be through an exchange in which SC Apache Tribe would essentially use Gila River water, and, in exchange, downstream users dependent on those supplies would receive CAP water allocated to the SC Apache Tribe. For the purpose of this analysis, this irrigation is assumed to occur on lands located in the river bottoms of the Gila and San Carlos Rivers, which are upstream of the San Carlos Reservoir. Other lands which have been identified as irrigable, such as those in the "Arsenic Flat" area of the Reservation, were not considered as a part of this scenario. Development of those lands would generally involve construction of much more extensive facilities than needed to develop lands along the Gila and San Carlos Rivers.

It is assumed that the lands would be irrigated by surface water diverted from the San Carlos Reservoir. On a conceptual level, the groundwater impact would be a limited rise in groundwater levels during the early years of irrigation, due to percolation of irrigation return flows and the resulting filling of presently dewatered alluvium. As groundwater levels rise, discharge to the San Carlos and Gila Rivers would increase. Eventually, a new groundwater "equilibrium" would be established, such that the discharge to the rivers would equal the irrigation return flows, and the return flows would be recaptured in San Carlos Reservoir.

A preliminary evaluation has been prepared to help quantify these impacts. Assumptions of the analysis include the following:

- Irrigated lands would be located over the stream alluvium and would be dispersed evenly on this alluvium on the Reservation (so that groundwater impacts should be estimated based on the total area of stream alluvium, rather than just the stream alluvium which directly underlies irrigated lands).

- The specific yield is 15 percent in the stream alluvium.

- The average unfilled storage is about 15 feet along the San Carlos River and about 50 feet along the Gila River.

- About five af per acre would be applied to irrigated lands, of which 2.5 af per acre would be consumptively used. The remaining 2.5 af per acre would recharge groundwater, to the extent that there is unfilled storage in the stream alluvium.

III.E.3. Analysis of Alternatives

Discussion is presented below regarding the effects of the alternatives on groundwater levels, groundwater quality, and subsidence. Because additional CAP water relative to present conditions would be used for all alternatives (including the No Action Alternative), the groundwater impacts are all similar and are discussed together for all alternatives in the following sub-sections which address groundwater levels, groundwater quality, and subsidence.

III.E.3.a. Groundwater Levels

A quantified evaluation of each alternative is presented in Table I-22. The volume of CAP water available for irrigation for each alternative reflects that a portion of the CAP allocation would be leased to others (see Appendices A and L). The total acres for each alternative are estimated by dividing the CAP irrigation supply by the application rate of five af per acre.

The estimated total stream alluvium acreage associated with the San Carlos and Gila Rivers is shown in Table I-22. The storage beneath each river was estimated based on that acreage, the average depth to water indicated from USGS WRI 89-4152 (about 15 feet for the San Carlos River and about 50 feet for the Gila River) and a 15 percent specific yield. All alternatives result in the same groundwater level impact by year 2051 (i.e., essentially filling available storage space). The time needed to fill this storage from irrigation return flows was then estimated by dividing the storage by the annual irrigation return flows.

The estimated time needed to fill this storage (ranging from about two to 10 years, depending on the alternative and the location) probably reflects an upper bound of the "lag time" before applications begin returning to San Carlos Reservoir. Depending on soil conditions and topography, there could be drainage issues associated with this intensity of irrigation on these lands.

III.E.3.b. Groundwater Quality

The impacts of alternatives on water quality for the SC Apache Tribe reflect use of water from the San Carlos Reservoir to irrigation lands associated with the Gila and San Carlos River Valleys. The quality of water in the San Carlos Reservoir was not identified directly. However, based on water quality measurements for the Gila River upstream of the reservoir, that quality probably varies. TDS concentrations tend to be about 600 to 700 ppm during low flow periods, and about 300 to 500 ppm during higher flow periods. It is anticipated that most of the flow would be captured during the higher flow periods and that the quality of water in the reservoir would reflect this. For the purpose of this analysis, it was assumed that the reservoir water would contain about 500 ppm of TDS.

For lands along the San Carlos River, the TDS concentration of the reservoir water is similar to that of the stream alluvium and upper portions of the basin fill aquifer. Therefore, water quality impacts are not expected in that area. The quality of San Carlos Reservoir water would tend to be better than the existing quality of groundwater associated with the Gila River. This indicates some potential for improved groundwater quality in the alluvium and basin fill materials associated with the Gila River.

III.E.3.c. Subsidence

Under all alternatives, additional lands would be irrigated with surface water supplies, which would result in potentially higher groundwater levels. Because groundwater level declines are not anticipated on the SC Apache Tribe lands, subsidence is not anticipated.

III.F. Groundwater Level Analysis for the TID

A hydrologic inventory analysis was performed for the TID. The location of TID is shown on Figure I-97. TID is located in the "Tonopah Desert" portion of the Hassayampa sub-basin of the Phoenix AMA, south of the Belmont and Big Horn Mountains, and north of the Gila Bend Mountains. The closest major drainage to TID is the Hassayampa River, located east of TID, which is an unregulated ephemeral stream tributary to the Gila River.

III.F.1. Existing Groundwater Conditions

The existing groundwater conditions were identified through review of several published sources, including the ADWR Hydrologic Map Series Report No. 10, the USBR 1976 Geology

Report, and the Pinal AMA Management Plans. The discussion which follows is based on those sources.

III.F.1.a. Geology

Groundwater occurs in the basin fill materials beneath and adjacent to TID. This fill includes the same three general units discussed in the earlier section on the Pinal and Salt River Valley areas. However, the Upper Alluvial Unit is generally de-watered in the Tonopah Desert area, so that the Middle Fine-Grained Unit and the Lower Conglomerate Unit generally comprise the aquifer in the basin fill for this area. Groundwater also occurs in volcanic bedrock underlying the Tonopah Desert. The total thickness of the basin fill and water-bearing volcanic bedrock is more than 1,200 feet in the central part of the Tonopah Desert.

III.F.1.b. Groundwater Occurrence and Movement

Groundwater in the Hassayampa area generally occurs under unconfined conditions. This includes the Tonopah Desert area in which TID is located.

The general pattern of groundwater flow in the Hassayampa basin is from north to south, with some flow going to the east to the northern portion of the West Salt River Valley. The Hassayampa basin also receives groundwater inflow from the West Salt River Valley area beneath the Gila River. In the Tonopah Desert area, the present pattern of flow is probably similar to that in 1982 (shown on Sheet 1 of the HMS No. 10). That map showed a groundwater depression generally located beneath TID which results in a radial pattern of flow toward that depression. Under pre-development conditions, flow was probably generally from the adjacent Belmont Mountains and Palo Verde Hills toward the center of the Tonopah Desert area, and then to the east toward the Hassayampa River.

Aquifer transmissivity was estimated based on specific capacity for selected wells, which indicated a range of aquifer transmissivity from about 18,000 to about 71,000 gallons per day (gpd) per foot. For the purpose of this analysis, the average aquifer transmissivity of about 38,000 gpd per foot from the specific capacity data was used. An estimate of specific yield was not located for the Tonopah Desert area. For this analysis, a value of nine percent has been used, which is similar to specific yield values shown for the lower alluvial unit in the West Salt River Valley area used in the ADWR model (as shown on Figure 5 of that report).

At a conceptual level, the primary recharge components of the hydrologic inventory would probably be groundwater inflow and incidental recharge from irrigation applications. Primary components of groundwater discharge would probably be groundwater underflow and groundwater pumping.

III.F.1.c. Groundwater Quality

Existing groundwater quality conditions were identified with respect to both general mineral constituents and for specific contaminants of interest.

III.F.1.c.(1). General Minerals

The TDS are considered as the general indicator of groundwater quality. The 1974 USGS Map I-845-G ("Dissolved-Solids Content of Ground Water in the Phoenix Area, Arizona") was used to define these conditions. Information on TDS was also reviewed from the TMP for the Phoenix AMA (Figure 7-3 of that document), and that information is consistent with USGS I-845-G. TDS concentrations of groundwater in the Tonopah Desert area were inferred by the USGS to be in the range of 500 to 1,000 ppm. In general, TDS concentrations tend to decrease with increasing depth (USGS Map I-844-L).

The general distribution of other constituents was identified from the 1974 USGS Map I-845-F ("Map Showing Chemical Quality of Ground Water for Public Supply in the Phoenix Area, Arizona") which shows the quality for the upper 300 feet of the saturated alluvium with respect to fluoride, nitrate, and hardness. This was supplemented with consideration of more recent water quality data presented in the TMP for the Tucson AMA. It appears that limited data were available for the Tonopah Desert area, but that groundwater generally contains fluoride in excess of 1.4 ppm.

III.F.1.c.(2). Other Constituents

No water quality study areas were identified in the Tonopah Desert area in the Phoenix AMA TMP.

III.F.1.d. Subsidence

Discussion of historical subsidence for the TID area was not located in available published reports. However, this lack of discussion could reflect that limited data are available to quantify any subsidence, or that damage or physical expression of subsidence that would prompt study using existing data has not occurred. For this reason, the geologic conditions were considered to evaluate the potential for subsidence.

Groundwater occurs in the "Lower Conglomerate Unit" and "Middle Fine-Grained Unit" beneath TID. The Middle Fine-Grained Unit is predominantly clay and silty clay, which would indicate some potential for subsidence. These deposits are similar to those in the Salt River Valley in which there has been substantial subsidence. Based on these considerations, lowering of groundwater levels in TID would be expected to have the potential to cause subsidence.

III.F.2. Details of Analysis Methodology

Because this area is relatively distant from other areas of intense groundwater development, a hydrologic inventory was developed for the TID area, rather than for a number of sub-areas as discussed for some of the other areas analyzed in this study. For the purpose of this analysis, the evaluation essentially considers all of TID and irrigated lands located south and west of TID. Information on historical hydrology is also relatively limited in this area, so that a number of assumptions were made, as documented in the following section.

III.F.3. Evaluation of Historical Conditions and "Calibration"

The hydrologic inventory analysis was used to evaluate groundwater levels from 1950 to 1999. Relatively limited data were available to evaluate historical groundwater levels in this area, so that a number of assumptions were made to perform this historical analysis.

Estimates were prepared for the components of the historical hydrologic inventory. These components include:

- ♦ Recharge
  - Groundwater inflows from margins of the analysis area
  - Incidental recharge

- ♦ Discharge
  - Groundwater outflows from margins of the analysis area
  - Groundwater pumping

The components of the hydrologic inventory were estimated based on limited available data and on judgment where data were not located.

A groundwater level hydrograph was prepared to compare groundwater levels estimated using the hydrologic inventory to groundwater levels in several wells in the area, as presented on Figure 98. This comparison indicates that the hydrologic inventory is able to reflect the large-scale trends in groundwater levels that have historically occurred.

III.F.4. Analysis of Alternatives

Groundwater levels were estimated for each alternative using the hydrologic inventory analysis, and groundwater level hydrographs are shown on Figure I-99 for all alternatives. As shown, groundwater levels are similar for all alternatives.

The results of the analysis are presented in two sub-sections, which discuss: (1) the No Action Alternative; and (2) the Settlement and Non-Settlement Alternatives. The No Action Alternative serves as the basis of comparison to determine impacts for the other alternatives. The discussion of the No Action Alternative, therefore, focuses to some extent on absolute groundwater level impacts, while discussion of the other alternatives focuses on impacts in comparison to the No Action Alternative.

III.F.4.a. No Action Alternative

Discussion is presented below regarding the effects of the alternatives on groundwater levels, groundwater quality, and subsidence.

III.F.4.a.(1). Groundwater Levels

Under the No Action Alternative, groundwater levels rise by more than 45 feet during the early years of the projection (from 2001 to 2016) and then decline through year 2051. From year 2001 to 2051, the net estimated impact is a decline in groundwater levels of about 17 feet.

The rise in groundwater levels from 2001 to 2016 reflects the availability of CAP water to the TID from both the Ag Pool and Recharge Pool. There is reduced availability of CAP water in later years. This reduced availability of CAP water essentially reverses the trend of rising groundwater levels, and groundwater levels drop through the remainder of the analysis period.

III.F.4.a.(2). Groundwater Quality

The No Action Alternative does not result in substantial changes in groundwater elevations and would not be anticipated to substantially change the pattern of groundwater flow near TID. Based on this, changes in groundwater quality are not anticipated.

III.F.4.a.(3). Subsidence

Under the No Action Alternative, estimated groundwater levels would be higher than the 2001 level for most of the 50-year analysis period, except for the very end of the period. At that time, groundwater levels would be about 17 feet deeper than in year 2001. Significant subsidence impacts would not be anticipated for that limited amount of groundwater level decline.

III.F.4.b. Settlement and Non-Settlement Alternatives

Discussion is presented below regarding the effects of the alternatives on groundwater levels, groundwater quality, and subsidence.

III.F.4.b.(1). Groundwater Levels

Under the Settlement and Non-Settlement Alternatives, groundwater levels in year 2051 would range from about 17 to 41 feet deeper than under the No Action Alternative. Those impacts are shown graphically on Figure I-100. Also shown is the change in the total excess CAP water over the 50-year analysis period (relative to excess CAP water available under the No Action Alternative). The excess CAP water includes the pools of CAP water that would be available to TID (i.e., the Ag Pool, CAP NIA allocations, and the Recharge Pool) The changes in the groundwater level impacts generally track with the changes in the total excess CAP water.

III.F.4.b.(2). Groundwater Quality

The Settlement and Non-Settlement Alternatives considered do not result in substantial changes in groundwater elevations, and would not be anticipated to substantially change the pattern of groundwater flow near TID. Based on this, changes in groundwater quality are not anticipated.

III.F.4.b.(3). Subsidence

The Settlement and Non-Settlement Alternatives all result in lower estimated groundwater levels than the No Action Alternative. There is some potential for subsidence impacts in TID under all alternatives.

III.G. Navajo/Hopi Indian Reservations

The potential impact of the CAP reallocation on groundwater underlying the Navajo and Hopi Indian Reservations was evaluated based on review of published studies. The analysis of impacts for the Navajo and Hopi Reservations was performed on a more qualitative basis than the analyses for other areas. This reflects several considerations, including the following:

- While the potential amount of CAP water available to both the Navajo and Hopi Tribes is known to be 13,500 afa for Non-Settlement Alternatives 2, 3A and 3B, the distribution of that water between the two Tribes is contingent on resolution of issues outside the scope of this draft EIS.

- Similarly, specifics on future water use are contingent on resolution of issues outside the scope of this draft EIS.

- The details of the physical groundwater system are still the subject of study, and firm values describing the physical system which has the consensus of the involved entities has not yet been developed.

The Navajo and Hopi Indian Reservations have an area of about 25,000 square miles, including lands in the northeastern part of Arizona, in New Mexico, and in Utah. Consistent with the Boulder Canyon Project Act, the analysis only considers those lands that are located in the Lower Colorado River Basin, and thus, can receive CAP water.

The analysis summarizes the Black Mesa hydrologic basin, as defined on Figure 1 of USGS Open-File Report 00-66 (Truini, Baum, Littin, and Shingoitewa-Honanie, 2000). That basin covers approximately 5,400 square miles, and includes all of the Hopi Indian Reservation lands, the Black Mesa Coal Mine, and the M&I use zones shown on Figure L-IND-4 of Appendix L. Most of the Black Mesa hydrologic basin is drained by the Little Colorado River and its various tributaries, although the eastern portion is drained by Chinle Wash. As shown on Figure 16 of USGS Professional Paper 521-A, most reaches of the drainages are intermittent, although there are some reaches that have been perennial for some period of time.

III.G.1. Existing Groundwater Conditions

Groundwater has been developed to supply a number of municipal and industrial uses in the Black Mesa basin. Groundwater supplies essentially all the domestic water needs of the population in the area. It also supplies the industrial needs, with the largest need being for a coal slurry pipeline for the Black Mesa Mine. Current groundwater conditions are described in the sections that follow.

III.G.1.a. Geology

The ADWR's "Hydrographic Survey Report for Indian Lands in the Lower Colorado River System" provides a summary discussion on the geology and was used to develop the discussion in this section. This was supplemented with information from the USGS studies in this area. The Navajo and Hopi Indian Reservations are underlain by about 1,000 to 10,000 feet of sedimentary rocks which overlay Precambrian igneous and metamorphic rocks. Recoverable groundwater generally occurs in sandstone layers between relatively impermeable siltstone and mudstone layers. While the siltstone and mudstone that separate these aquifers are relatively impermeable, there are fractures in these layers which allow some flow between the various aquifer units.

Three principal aquifers have been identified in the area. The deepest aquifer is the Coconino or C-Aquifer. This extensive aquifer which underlies most of the two Reservations has an average thickness of about 400 feet. The Navajo/Lukachukai Aquifer or N-Aquifer is above the C-Aquifer. It underlies the northwestern portion of the Navajo Reservation and the Hopi Indian Reservation. USGS WSP 561-A indicates that the N-Aquifer has an average thickness of about 400 feet. The Dakota/Cow Springs Aquifer or D-Aquifer underlies the Hopi Reservation and the north-central portion of the Navajo Reservation. It occurs as isolated, semi-connected aquifers.

According to USGS WSP 2201, the N-Aquifer is the main source of groundwater in the Black Mesa area. Most wells in the Black Mesa area do not tap into the deeper C-Aquifer. The USGS (WSP 2201) indicated that there is not significant movement of groundwater between the N- and C-Aquifers in the Black Mesa area. The D-Aquifer, which overlies the N-Aquifer, provides some water supply for uses along the Shonto Wash in the northern portion of the Black Mesa area. Leakage from the D-Aquifer also provides water to the N-Aquifer. Based on this, the remainder of the discussion and the analysis of impacts focus on the N-Aquifer.

The N-Aquifer is more than 1,200 feet thick at Kaibito. It thins and eventually "pinches out" to the west. The analysis herein considers the portion of the N-Aquifer modeled by the USGS, as shown on Figure I-101. The N-Aquifer extends northwesterly of the area modeled by the USGS, at the location of a groundwater flow divide. The thickness of the N-Aquifer in the area modeled by the USGS ranges from less than 100 feet in the south to over 900 feet near the Black Mesa Coal Mine.

III.G.1.b. Groundwater Occurrence and Movement

Groundwater occurs under confined and unconfined conditions in the N-Aquifer. The N-Aquifer outcrops along the eastern, northern, and western edges of the Black Mesa area, and water in those areas is generally unconfined.

Groundwater level contours for 1969, shown on Figure I-101, indicate groundwater flow was from Shonto south and southeast toward the location of the present Black Mesa Coal Mine. From there, some flow travels to the west toward Moenkopi Wash as well as easterly and northeasterly toward Laguna Creek and Chinle Wash. The USGS Water-Resources

Investigations Report 96-4190 (1997) also indicated that the same general pattern of flow was present in 1996, with some changes in flow reflecting pumping at the mine and the associated local lowering of groundwater levels.

III.G.1.c. Groundwater Quality

Table 12 of USGS Open-File Report 00-16 (2000) presents ranges of concentrations of chemical constituents for the various aquifers that underlie the Navajo and Hopi Indian Reservations, including the Navajo Aquifer. Ranges for selected constituents are summarized below:

Sulfate	1.6 to 250 mg/l
Chloride	1.3 to 140 mg/l
Total Dissolved Solids	94 to 714 mg/l

III.G.1.d. Subsidence

Groundwater supplies have primarily been developed from consolidated sedimentary rocks. Subsidence would not be a concern for this geologic condition, and so is not included in the discussion of alternatives.

III.G.2. Details of Analysis Methodology

The qualitative evaluation was developed based on consideration of the conceptual (rather than a quantified) hydrologic inventory for the N-Aquifer, using information from the available published sources. The groundwater flow pattern discussed above indicates that percolation of precipitation on the outcrop areas, and particularly in the Shonto area, provides some recharge. The flow pattern also indicates discharge from the aquifer to the Moenkopi Wash at the western end of the N-Aquifer, and to Laguna Creek and Chinle Wash to the east and northeast.

As discussed in USGS WSP 2201, field data are not adequate to quantify the hydrologic inventory. However, that report does present an estimated budget for pre-development conditions (pre-1964) and for development conditions (1979) prepared during the modeling process. The pre-development condition shows a balance between recharge and discharge. For the 1979 condition, there is a decrease in storage, reflecting that the withdrawals have only had a minor impact in reducing discharges to springs, streams, alluvium, and evapotranspiration.

The specific yield values used in the USGS model for unconfined areas ranged from 0.10 to 0.15 (10 to 15 percent). The storage coefficient for the confined areas (similar to the specific yield for an unconfined aquifer, except that it represents water yielded from the aquifer through a unit drop in the pressure head, rather than dewatering of a unit volume) used in the USGS model was about 0.0004. This value is several orders of magnitude smaller than the specific yield for the unconfined areas and indicates that the storage in the confined areas of the N-Aquifer is negligible in comparison to the storage in the unconfined areas.

As presented in USGS progress reports and results of the Black Mesa N-Aquifer monitoring program (1978 through 2000, Open-File Reports and Water-Resources Investigations Reports), groundwater levels observed in wells in the unconfined areas have been relatively stable over time and water levels have declined in the confined areas. This is consistent with the observations made in USGS WSP 2201 stating that, while water has been taken out of storage over this period, the change in storage is minimal with respect to the total volume of water in storage in the Black Mesa area. In contrast, groundwater levels have dropped-in areas of the confined aquifer where pumping has occurred. The groundwater level declines reflect changes in the levels required to induce groundwater flows rather than changes in storage.

In order to provide some indication of the potential impact of CAP availability on groundwater levels, a simple computation was made of the potential incremental difference in groundwater storage in year 2051 with the CAP allocation versus without the CAP allocation. The total volume of CAP water would be about 675,000 af (13,500 afa multiplied by 50-year analysis period).

To the extent that the CAP water offsets groundwater pumping, the incremental difference in groundwater storage would be an increase of 675,000 af with the availability of CAP water. By comparison, USGS WSP 2201 indicates that the total storage in the N-Aquifer was at least 180,000,000 af in 1964, and that there have only been limited withdrawals from the aquifer since 1964. More recent findings by the USGS (Water-Resources Investigation Report 96-4190, 1997) indicate storage in the saturated N-Aquifer to be 293,000,000 af. These values indicate that the CAP water potentially available would result in an incremental increase of groundwater storage in the N-Aquifer of 0.23 to 0.38 percent.

III.G.3. Analysis of Alternatives

Due to the qualitative nature of the analysis, evaluation of alternatives was limited to identifying potential incremental differences in the volume of groundwater in storage. This evaluation is presented in the sub-sections that follow, which discuss the No Action Alternative and the Settlement and Non-Settlement Alternatives.

III.G.3.a. No Action Alternative

Under the No Action Alternative, the Navajo and Hopi Tribes would not receive CAP water. The impacts of the Settlement and Non-Settlement Alternatives would be measured by the incremental change in groundwater storage equal to the CAP water received for those alternatives.

The drawdown effects of ongoing N-Aquifer withdrawals will be greatest near the centers of pumping. The greatest withdrawals from the confined part of the aquifer are at the Peabody mining complex, and the communities of Kayenta, Pinon and Polacca. The greatest withdrawals from the unconfined part of the aquifer are at the communities of Tuba City, Shonto and Moenkopi. N-Aquifer characteristics that determine the response to pumping vary greatly throughout the basin. Accurately predicting local impacts requires analyses outside the scope of this EIS. However, it is likely that future drawdowns in certain local areas will be substantial, and could impair the ability to recover groundwater using existing wells.

III.G.3.b. Settlement and Non-Settlement Alternatives

CAP water would not be available under the Settlement Alternative and Non-Settlement Alternative 1. Therefore, there would not be an incremental change in groundwater storage for these alternatives relative to the No Action Alternative.

The additional increment of CAP water under Non-Settlement Alternatives 2, 3A and 3B would result in a reduction in groundwater pumping of 675,000 af over the 50-year period. This would result in an incremental increase in groundwater storage relative to the No Action Alternative of 675,000 af or about 0.23 to 0.38 percent of the overall N-Aquifer storage. The increased groundwater storage would result in higher average groundwater levels overall in the N-Aquifer for these alternatives relative to the No Action Alternative. However, as previously discussed, evaluation of local impacts is outside the scope of this draft EIS, and the improvement in overall N-Aquifer storage may not translate into significant improvements in groundwater levels for all local areas that experience substantial drawdowns under the No Action Alternative.

III.H. Carefree Sub-basin

The community of Cave Creek obtains groundwater from the Carefree sub-basin of the Phoenix AMA. Discussion presented herein is largely based on information presented in the Phoenix AMA Management Plans and in the 1974 ADWR report "Arizona Water Resources Assessment."

The total area of the sub-basin (which includes lands underlain by both basin fill and alluvium) is about 140 square miles. The developed lands (including the Cave Creek and Carefree communities) are located in the southern portion of the basin, while the northern area includes mountainous undeveloped desert lands. The area is drained by the ephemeral Cave Creek, which flows from north to south across the sub-basin. For the purpose of this analysis, groundwater conditions were evaluated in the portion of the Carefree sub-basin that is underlain by the valley fill and which is within the Municipal Planning Area (MPA) for Cave Creek. That area (about 14 square miles) is shown on Figure I-102.

III.H.1. Existing Groundwater Conditions

The sub-sections which follow summarize information on the geology and the occurrence and movement of groundwater in the Carefree sub-basin. The information has have largely been taken from the 1974 ADWR report "Arizona Water Resources Assessment" and the Management Plans for the Phoenix AMA.

III.H.1.a. Geology

The Carefree sub-basin is underlain by partially consolidated to consolidated sedimentary rocks, which are as much as about 2,000 feet thick. The primary aquifer consists of alluvial fan and playa deposits. These deposits are underlain by volcanic rocks (which do not yield significant water to wells) and weathered granite (in which well yields of as much as 600 gpm have been achieved). The ADWR report characterized the weathered granite as "a potential future source of groundwater," which indicates only limited development to date.

III.H.1.b. Groundwater Occurrence and Movement

Groundwater level contours for 1992 are shown on Figure 2-5 of the draft TMP for the Phoenix AMA. Those contours show that a groundwater depression has developed in the portion of the Carefree sub-basin considered in this analysis.

III.H.1.c. Groundwater Quality

The ADWR's report "Arizona Water Resources Assessment" indicates that in general, groundwater in the Carefree sub-basin is suitable for most uses, including domestic use. TDS concentrations were indicated to range from about 200 to 700 ppm in 1977. Fluoride concentrations ranged from 0.5 to 8.0 ppm.

III.H.1.d. Subsidence

Discussion of historical subsidence for the Carefree sub-basin was not located in published reports. Portions of this sub-basin have experienced groundwater level declines. The lack of discussion could reflect that limited data are available to quantify any subsidence or that damage or physical expression of subsidence that would prompt study with existing data has not occurred. For this reason, the geologic conditions were considered to evaluate if subsidence could occur in this area.

As described earlier in the section on groundwater level impacts, the basin fill materials include partially consolidated to consolidated sedimentary rocks. Consolidated sedimentary rocks would be anticipated to be less susceptible to subsidence. While not definitive, this indicates that there may be less potential for subsidence in the Carefree sub-basin that in the basin fill materials located in the adjacent East Salt River Valley area.

III.H.2. Details of Analysis Methodology

Because this area essentially covers a separate groundwater basin, a hydrologic inventory was developed for the portion of the Carefree sub-basin within the Cave Creek MPA, rather than for a number of sub-areas, as discussed for some of the other areas analyzed in this study.

III.H.3. Evaluation of Historical Conditions and "Calibration"

The hydrologic inventory analysis was used to evaluate groundwater conditions from about 1955 to 1999. Estimates were prepared for the components of the historical hydrologic inventory. Information presented in the 1994 ADWR report "Arizona Water Resources Assessment" indicates that major components of the hydrologic inventory for the Carefree sub-area are:

- Recharge
  - Mountain front recharge in northeast and east
  - Streambed recharge from Cave Creek in northwest
  - Recharge from ephemeral washes

- Discharge
  - Groundwater outflow in Cave Creek alluvium to the south
  - Groundwater pumping

These components were estimated for the 1955 to 1999 period based on limited data presented in the ADWR "Arizona Water Resources Assessment" and in the TMP for the Phoenix AMA. Judgment was used to extrapolate from data presented in those documents.

Average estimated groundwater levels from 1955 to 1999 based on the hydrologic inventory analysis are shown on Figure I-103 as is a selected historical groundwater level hydrograph. The hydrologic inventory shows a trend of declining groundwater levels. The hydrograph also shows decline but also has much more variability in groundwater levels. There is a limited correspondence of the levels estimated using the hydrologic inventory to the well hydrograph. It may reflect, at least in part, that the hydrologic inventory result represents an average groundwater level for the entire sub-basin, while the hydrograph reflects the level at a specific well.

III.H.4. Analysis of Alternatives

Groundwater levels were estimated for each alternative using the hydrologic inventory analysis. Ground level hydrographs are shown on Figure I-104 for all alternatives. The results of the analysis are presented in two sub-sections, which discuss: (1) the No Action Alternative; and (2) the Settlement and Non-Settlement Alternatives. The No Action Alternative serves as the basis of comparison to determine impacts for the other alternatives. The discussion of the No Action Alternative, therefore, focuses to some extent on changes in absolute groundwater level over the 2001 to 2051 period, while discussion of the other alternatives focuses on impacts in comparison to the No Action Alternative.

III.H.4.a. No Action Alternative

The sub-sections which follow discuss the effects of the No Action Alternatives on groundwater levels, groundwater quality, and subsidence.

III.H.4.a.(1). Groundwater Levels

Under the No Action Alternative, groundwater levels would rise during the early years of the analysis. That rise reflects full use of available CAP supplies to meet demands. Groundwater pumping increases over time to meet the additional demands and that increased groundwater pumping eventually results in groundwater level declines later in the analysis period. Over the entire 50-year period, groundwater levels decline by about 13 feet.

III.H.4.a.(2). Groundwater Quality

Changes in groundwater quality in the Carefree sub-basin would not be expected for the No Action Alternative. This reflects consideration that: (1) the flow pattern would probably not be modified; (2) no well-defined bodies of groundwater of differing quality at various depths were identified; and (3) CAP water is not being directly recharged.

III.H.4.a.(3). Subsidence

Under the No Action Alternative, estimated groundwater levels would decline by about 12 feet from 2001 to 2051. This small amount of estimated groundwater level decline and the limited potential for subsidence in consolidated deposits indicate that subsidence impacts would not be anticipated in the Carefree sub-basin.

III.H.4.b. Settlement and Non-Settlement Alternatives

The subsections which follow discuss the impacts of these alternatives on groundwater levels, groundwater quality, and subsidence.

III.H.4.b.(1). Groundwater Levels

The impacts of each alternative reflect the changes in the availability of CAP water under that alternative. The Non-Settlement Alternatives 2 and 3A would have the same CAP supplies and groundwater pumping amounts as the No Action Alternative. Therefore, there would not be groundwater level impacts for these alternatives relative to the No Action Alternative.

Under the Settlement Alternatives and Non-Settlement Alternatives 2 and 3B, groundwater levels would be higher than under the No Action Alternative, resulting in positive groundwater level impacts. The positive impacts reflect the additional CAP water supplies available under these alternatives. In year 2051, groundwater levels are estimated to be 58 feet higher than under the No Action Alternative (in other words, these alternatives have a positive impact of 58 feet on groundwater levels).

III.H.4.b.(2). Groundwater Quality

Changes in groundwater quality relative to the No Action Alternative in the Carefree sub-basin would not be expected for any of the alternatives. This reflects consideration that: (1) the flow pattern would probably not be greatly modified; (2) no well-defined bodies of groundwater of differing quality at various depths were identified; and (3) CAP water is not being directly recharged.

III.H.4.b.(3). Subsidence

The Non-Settlement Alternatives 2 and 3A would have the same estimated groundwater levels as the No Action Alternative. Therefore, similar to the No Action Alternative, subsidence would not be anticipated for these alternatives.

The Settlement Alternative and Non-Settlement Alternatives 1 and 3B would have higher estimated groundwater levels in year 2051 than the No Action Alternative. Subsidence would not be anticipated for these alternatives.

III.I. Chaparral Area of Fountain Hills Sub-Basin

The Chaparral City Water Company obtains groundwater from the Fountain Hills sub-basin of the Phoenix AMA. Limited data were located for that area, and the discussion presented herein is largely based on information presented in the Phoenix AMA management plans and in the 1994 ADWR report "Arizona Water Resources Assessment."

The total area of the sub-basin (which includes lands underlain by both basin fill and alluvium) is about 360 square miles. Major drainages are the perennial Verde River (which is regulated by the upstream Bartlett Dam) and the Salt River between Stewart Mountain Dam and Granite Reef Dam. There are also several intermittent drainages tributary to the Verde River. Figure I-105 shows the Chaparral/Fountain Hills MPA in relation to the Fountain Hills sub-basin of the Phoenix AMA. Groundwater conditions were evaluated for the portion of the Chaparral/Fountain Hills MPA that overlies the alluvium and basin fill.

III.I.1. Existing Groundwater Conditions

Limited information was available on existing groundwater conditions. The sub-sections which follow discuss the geology, occurrence and movement of groundwater, groundwater quality, and subsidence based on those limited data.

III.I.1.a. Geology

Groundwater occurs primarily within unconsolidated alluvium associated with the Verde River and in the deeper basin fill materials. The unconsolidated alluvium is generally about one mile wide along the Verde River and more than 90 feet thick. It consists of gravel, sand, and sandy silt.

The thickness of the basin fill varies, with the depth to bedrock exceeding 1,200 feet in the center of the valley. The basin fill deposits include fanglomerate at basin margins and grade into interbedded fine sand, silt and clay toward the center of the basin. Near the center of the basin, the materials are predominantly clays, silts, and evaporites.

In some areas, there is some hydraulic separation of the unconsolidated alluvium and the basin fill by clay materials.

III.I.1.b. Groundwater Occurrence and Movement

As noted in the available references, there are few wells in the Fountain Hills sub-basin, so that the occurrence and movement of groundwater are less well defined than many of the other areas considered in this document. Groundwater generally flows from north to south (paralleling the flow in the Verde River), and there is likely also lateral flow from the margins of the valley to the center of the valley. The 1994 ADWR "Arizona Water Resources Assessment" indicates that this pattern of flow is probably relatively unchanged from the pre-development conditions. The ADWR Hydrologic Map Series Report 27 shows a few contours in the vicinity of the Chaparral/Fountain Hills MPA for 1991-92. Flow is generally southwesterly, including a component of flow from the Verde River toward the Chaparral area.

Information on confinement was not presented in the materials reviewed. Based on judgment, considering the relatively coarse nature of the unconsolidated alluvium, it is considered likely that groundwater in those materials would be unconfined. In the deeper basin fill deposits, it seems likely that the tendency of the deposits to become finer grained toward the center of the valley would result in a greater level of confinement in the center of the valley.

III.I.1.c. Groundwater Quality

As discussed earlier with regard to existing groundwater level conditions in the Fountain Hills sub-basin, limited data are available on existing groundwater quality conditions. The ADWR's 1994 report "Arizona Water Resources Assessment" indicates that, in general, groundwater in the Fountain Hills sub-basin is suitable for most uses, including domestic. TDS concentrations were indicated to range from about 300 to 850 ppm in the early 1980s**.** Fluoride concentrations ranged from 0.4 to 9.2 ppm.

III.I.1.d. Subsidence

Discussion of historical subsidence for the Carefree sub-basin was not located in published reports. Portions of this sub-basin have experienced groundwater level declines. The lack of discussion could reflect that limited data are available to quantify any subsidence, or that damage or physical expression of subsidence that would prompt study with existing data has not occurred. For this reason, the geologic conditions were considered to evaluate if subsidence could occur in this area.

As described earlier in the section on groundwater level impacts, the basin fill materials include partially consolidated to consolidated sedimentary rocks. Consolidated sedimentary rocks would be anticipated to be less susceptible to subsidence. While not definitive, this indicates that there may be less potential for subsidence in the Carefree sub-basin than in the basin fill materials located in the adjacent East Salt River Valley area.

III.I.2. Methodology

A hydrologic inventory analysis was developed for the Chaparral sub-area (corresponding to the portion of the Chaparral MPA which overlies basin fill in the Fountain Hills sub-basin). For the Chaparral sub-area, components considered include incidental recharge and groundwater underflow from the east and estimated groundwater pumping.

III.I.3. Evaluation of Historical Conditions

The hydrologic inventory analysis was used to evaluate groundwater conditions from about 1990 to 1999. Estimates were prepared for the components of the historical hydrologic inventory. Components evaluated for the historical hydrologic inventory are:

- Recharge
  - Groundwater inflows from margins of the analysis area
  - Incidental recharge

- Discharge
  - Groundwater outflows from margins of the analysis area
  - Groundwater pumping

The components of the hydrologic inventory were estimated based on limited available data and on judgment where data were not located.

Historical groundwater levels estimated using the hydrologic inventory and measured in wells are shown on Figure I-106. Both the hydrographs and the groundwater levels estimated using the hydrologic inventory analysis show relatively stable groundwater levels. This is consistent with the assessment (presented earlier) that the groundwater flow pattern has probably not changed significantly from the pre-development conditions.

III.I.4. Analysis of Alternatives

Groundwater level impacts for each alternative were estimated using the hydrologic inventory analysis. The results of the analysis are presented in two sub-sections which discuss: (1) the No Action Alternative; and (2) the Settlement and Non-Settlement Alternatives. The No Action Alternative serves as the basis of comparison to determine impacts for the other alternatives. The discussion of the No Action Alternative, therefore, focuses to some extent on changes in absolute groundwater level over the 2001 to 2051 period, while discussion of the other alternatives focuses on impacts in comparison to the No Action Alternative.

III.I.4.a. No Action Alternative

Effects on groundwater levels, groundwater quality, and subsidence for the No Action Alternative are summarized in the sub-sections which follow.

III.I.4.a.(1). Groundwater Levels

Estimated groundwater levels for the No Action Alternative are shown on Figure I-107. As shown, groundwater levels would rise by about 14 feet during the first 10 years of the projection period. This reflects relatively plentiful CAP supplies relative to demands during that period. As the demands continue to increase, the groundwater pumping would also increase, resulting in falling groundwater levels for the remainder of the period. From year 2001 to 2051, the average groundwater level would fall about 50 feet.

III.I.4.a.(2). Groundwater Quality

Changes in groundwater quality in the vicinity of Chapparal City Water Company would not be expected for the No Action Alternatives. This reflects consideration that: (1) the flow pattern would probably not be modified; (2) no well-defined bodies of groundwater of differing quality at various depths were identified; and (3) CAP water is not being directly recharged.

III.I.4.a.(3). Subsidence

Under the No Action Alternative, estimated groundwater levels would decline by about 50 feet from 2001 to 2051. There would be a potential for subsidence impacts under the No Action Alternative. However, this conclusion is tentative, given that the basin has not been stressed historically to the extent needed to confirm the subsidence potential with the same level of confidence as in the adjacent East Salt River Valley area.

III.I.4.b. Settlement and Non-Settlement Alternatives

Groundwater level, groundwater quality, and subsidence impacts for these alternatives are summarized in the sub-sections which follow.

III.I.4.b.(1). Groundwater Levels

Estimated groundwater levels for these alternatives are shown on Figure I-107. The impacts of each alternative reflect the changes in the availability of CAP water under that alternative. The Non-Settlement Alternatives 2 and 3A would have the same CAP supplies and groundwater pumping amounts as the No Action Alternative. Therefore, there would not be groundwater level impacts for these alternatives relative to the No Action Alternative.

The groundwater level trends for the Settlement Alternative and Non-Settlement Alternatives 1 and 3B are similar to the No Action Alternative, except that more plentiful CAP supplies extend the period of groundwater rise (to about 15 years) and reduce the decline in the later years. From 2001 to 2051, the average groundwater level would fall about 30 feet. The Settlement Alternative and Alternatives 1 and 3B would have a positive 20-foot impact on groundwater levels (in other words, groundwater levels would be 20 feet higher than under the No Action Alternative).

III.I.4.b.(2). Water Quality

Changes in groundwater quality in the vicinity of Chapparal City Water Company would not be expected for any of the alternatives. This reflects consideration that: (1) the flow pattern would probably not be modified; (2) no well-defined bodies of groundwater of differing quality at various depths were identified; and (3) CAP water is not being directly recharged.

III.I.4.b.(3). Subsidence

The Non-Settlement Alternatives 2 and 3A would have the same estimated groundwater levels as the No Action Alternative. Therefore, these alternatives would not have subsidence impacts (i.e., subsidence would not differ from the No Action Alternative).

The Settlement Alternative and Non-Settlement Alternatives 1 and 3B would have higher groundwater levels than the No Action Alternative. Therefore, these alternatives would have positive subsidence impacts relative to the No Action Alternative (i.e., less potential for subsidence than the No Action Alternative). However, it is noted that groundwater levels would be about 30 feet deeper than in the No Action Alternative, so that there would still be some potential for some subsidence under these alternatives.

APPENDIX I LIST OF REFERENCES

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